MSFC-440

Hinode Observations of the Onset Stage of a Solar Filament Eruption

A. C. Sterling, R. L. Moore, and the Hinode Team

We use Hinode X-Ray Telescope (XRT) and Solar Optical Telescope (SOT) filtergraph (FG) Stokes-V magnetogram observations, to study the early onset of a solar eruption that includes an erupting filament that we observe in TRACE EUV images. The filament undergoes a slow rise for about 20 min prior to its fast eruption and strong soft X-ray flaring, and the new Hinode data elucidate the physical processes occurring during the slow-rise period. Magnetic flux cancelation occurs along the neutral line of the filament, beginning several hours before eruption. During the slow-rise phase, a soft X-ray (SXR) sigmoid forms from apparent reconnection low in the sheared core field traced by the filament, and there is a low-level intensity peak in both EUV and SXRs at the start of the slow rise.

MSFC-448

Hinode Observations of the Onset Stage of a Solar Filament Eruption

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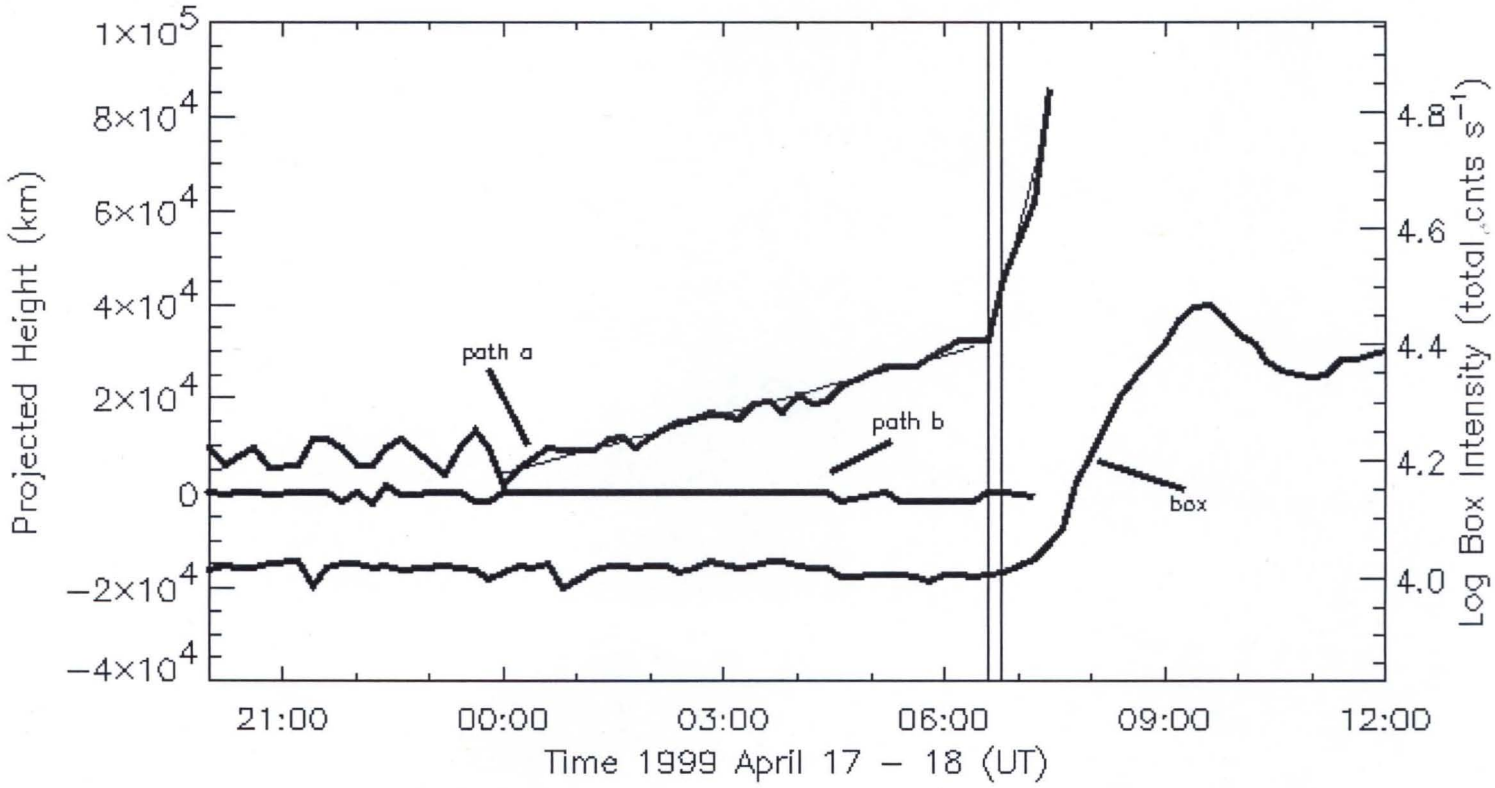
Introduction

- Trying to understand solar eruptions.
- Using filaments as tracers of the erupting field.
- Detailed examination of several individual events.
- Today we present our first Hinode-observed filament eruption, from 2007 March 2.
- **First question addressed:** What leads to pre-eruption **slow rise** of filaments?

Filament pre-eruption, pre-flare **slow-rise phase**



Sterling, Moore, Thompson (2001)

(e.g., Tandber-Hanssen et al. 1980, Kahler et al. 1988)

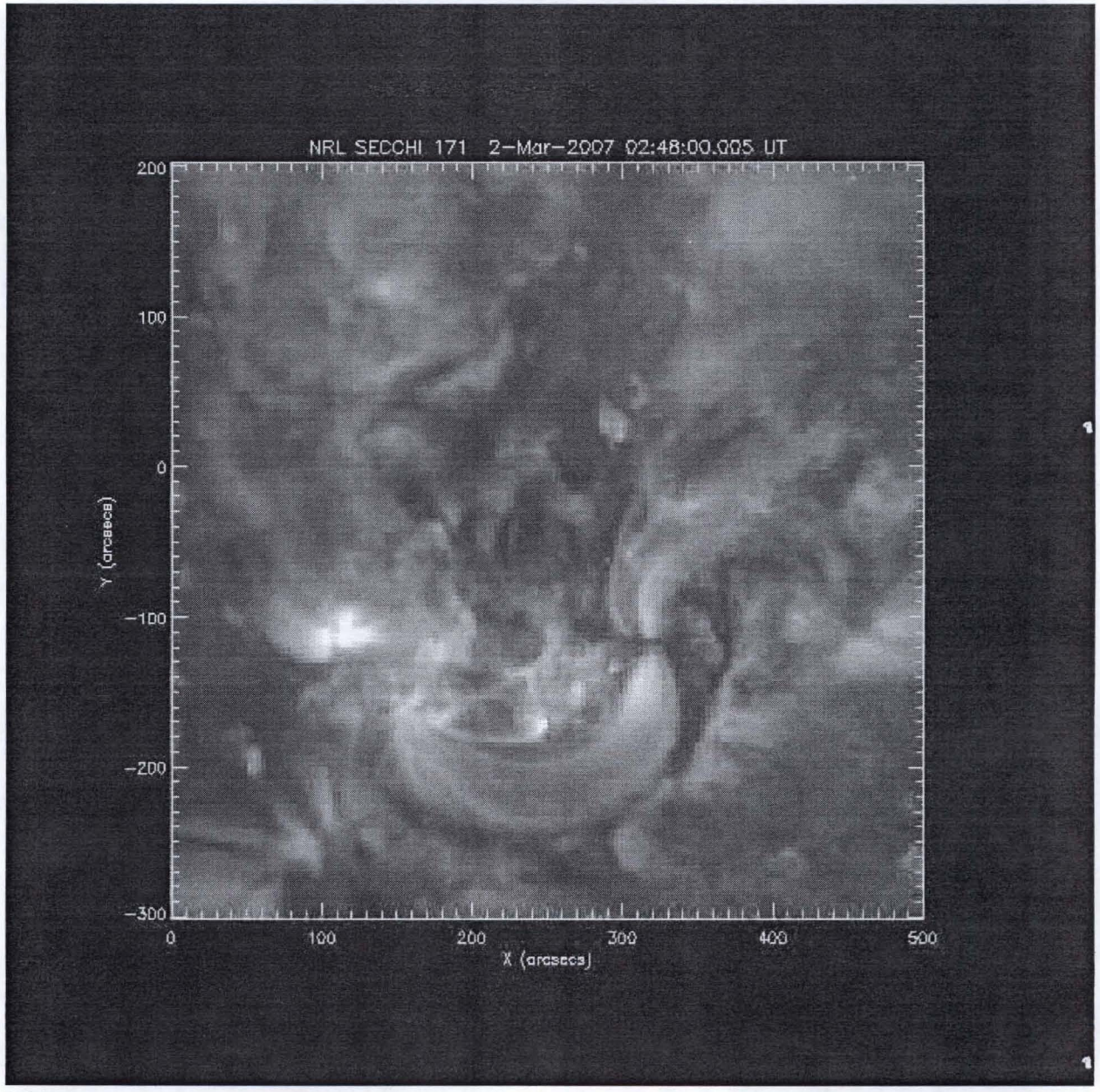
Hinode Event: Data Sets

- On-disk filament eruption of 2 March 2007. GOES class B 2.5.
- Seen with TRACE, STEREO, Hinode.
- Use TRACE for filament
- Hinode:
  - SOT (FG V magnetogram), etc.
  - SXRs from XRT
- Also use MDI magnetogram

Image Alignment

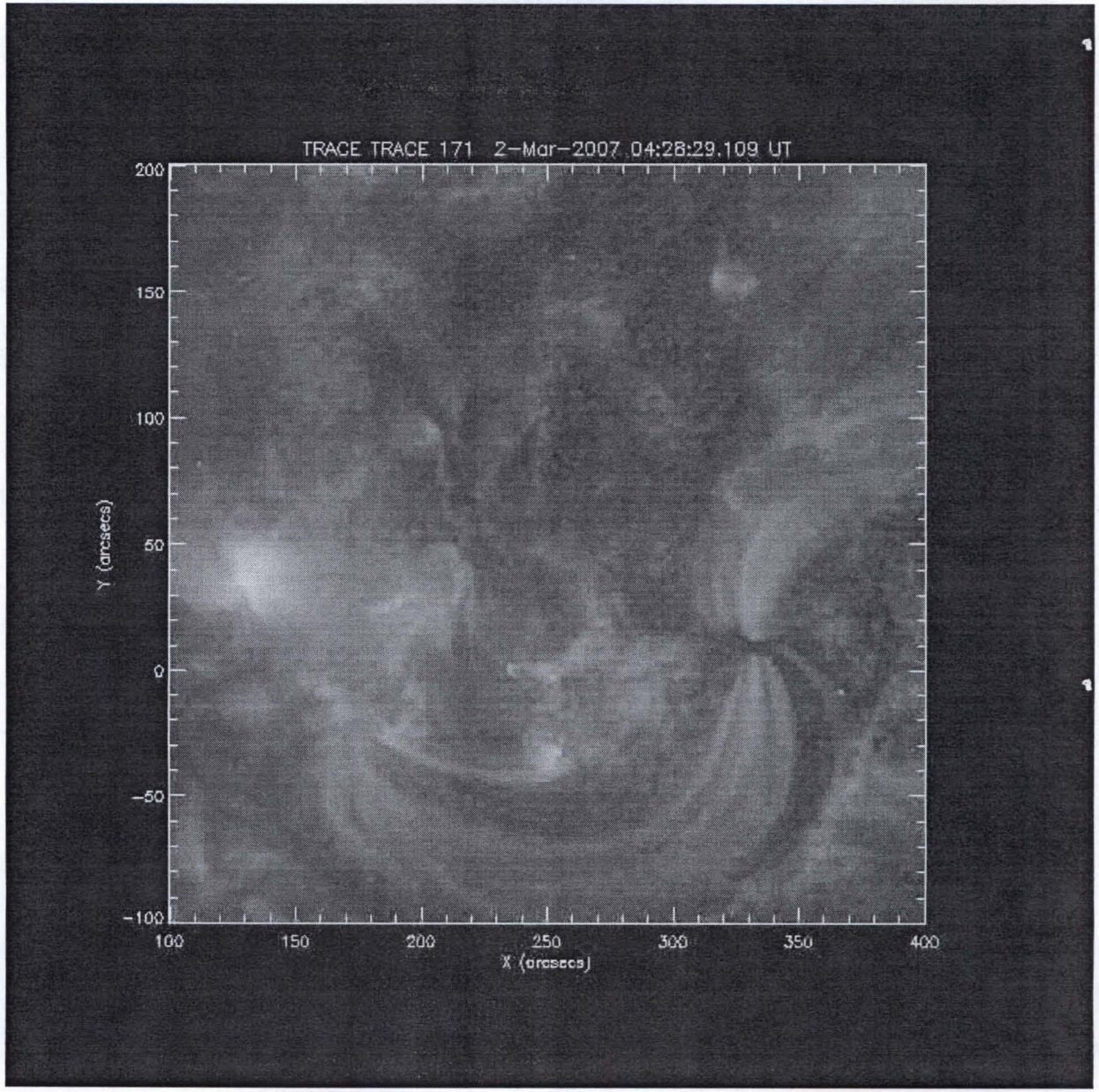
- TRACE on MDI: both alignments known.
- Match SOT and MDI magnetograms => SOT on MDI, TRACE.
- XRT onto SOT: Internal Hinode studies (H. Hara, N. Narukage; private communication), plus "by eye." => XRT onto MDI, TRACE.

STEREO 171



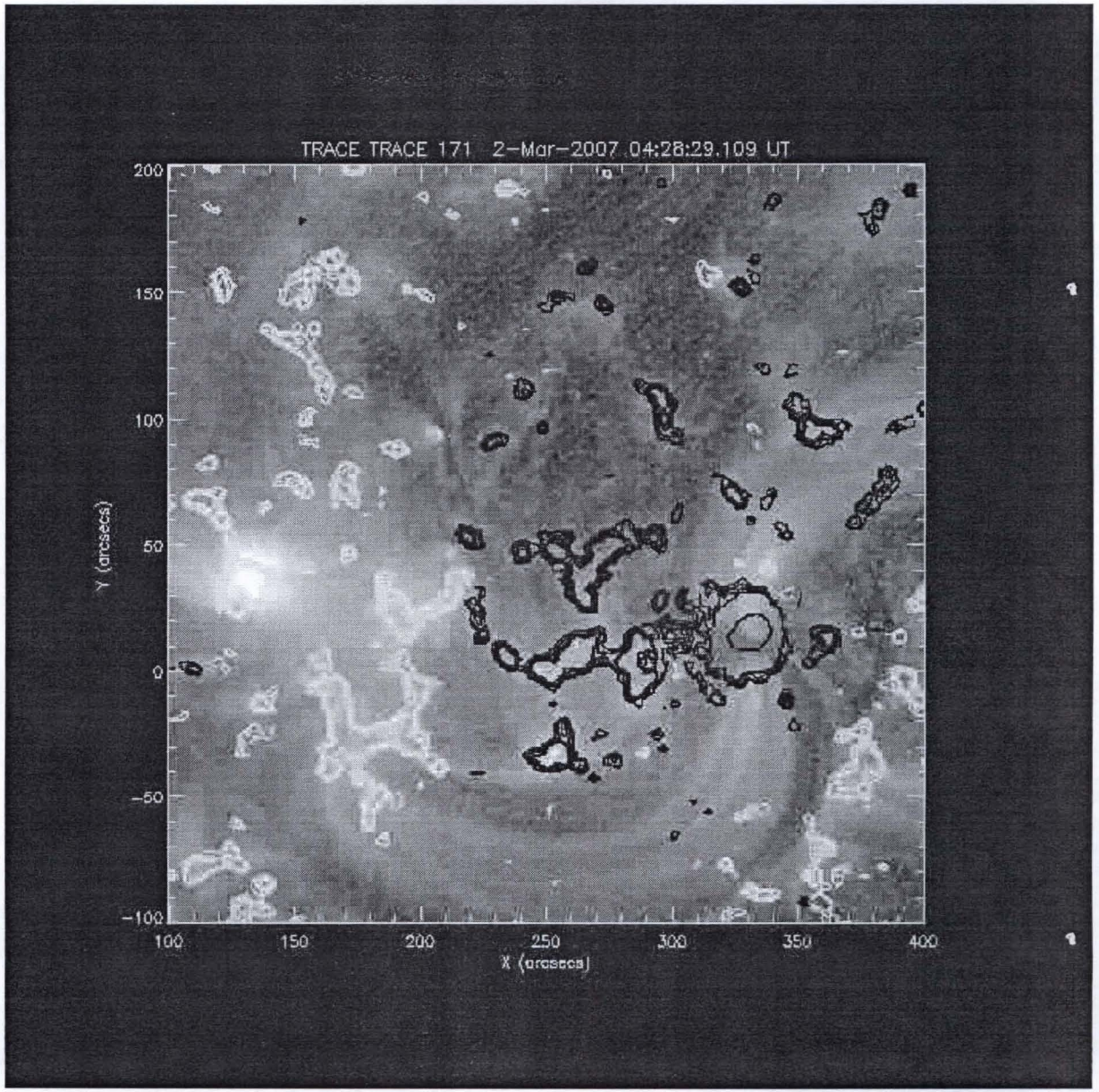
Sterling, Dublin 2007

TRACE 171



Sterling, Dublin 2007

TRACE on MDI



Sterling, Dublin 2007

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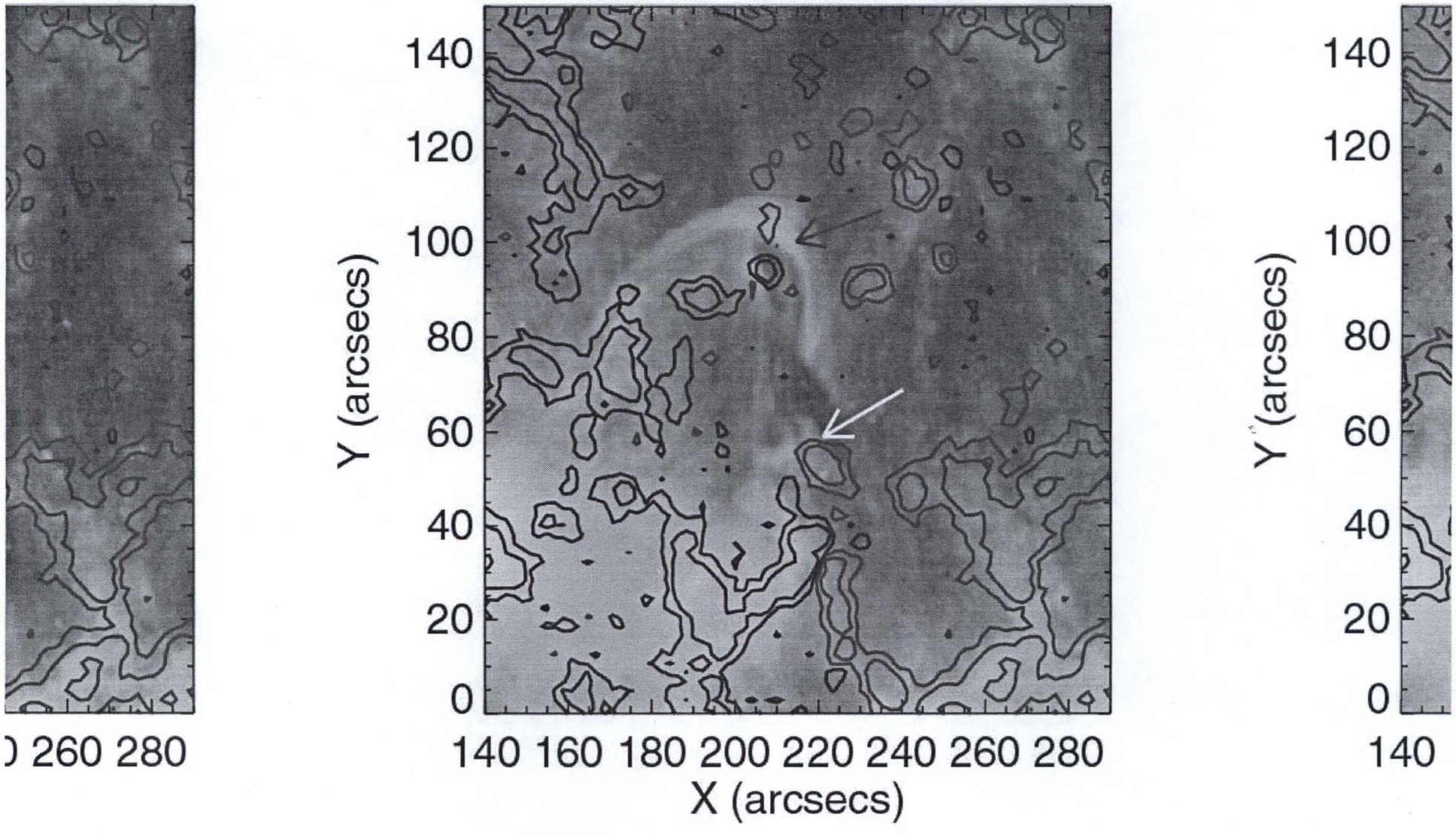
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(b) TRACE 171: 2-Mar-2007 04:47:41
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Y (arcsecs)
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X (arcsecs)
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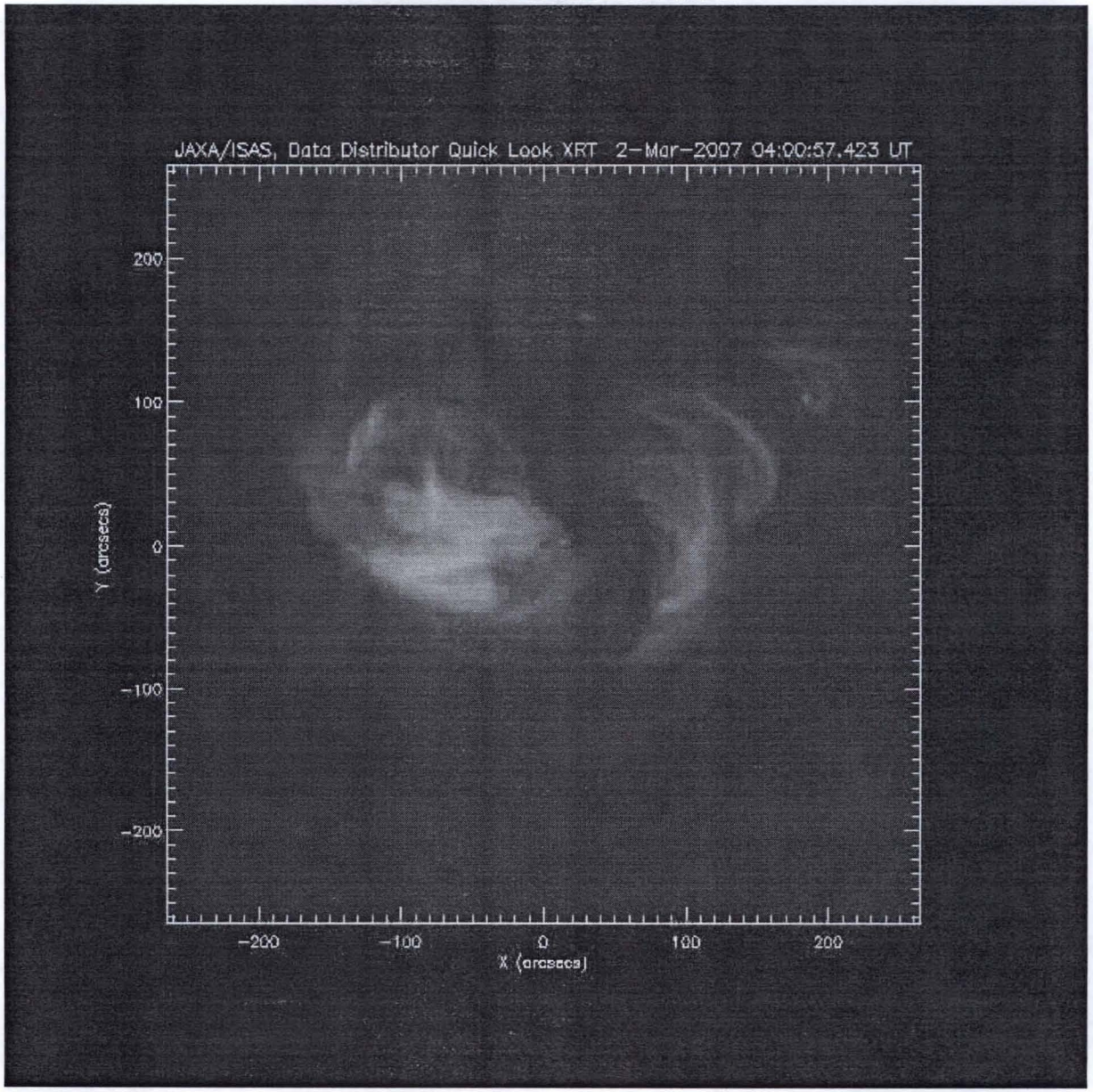
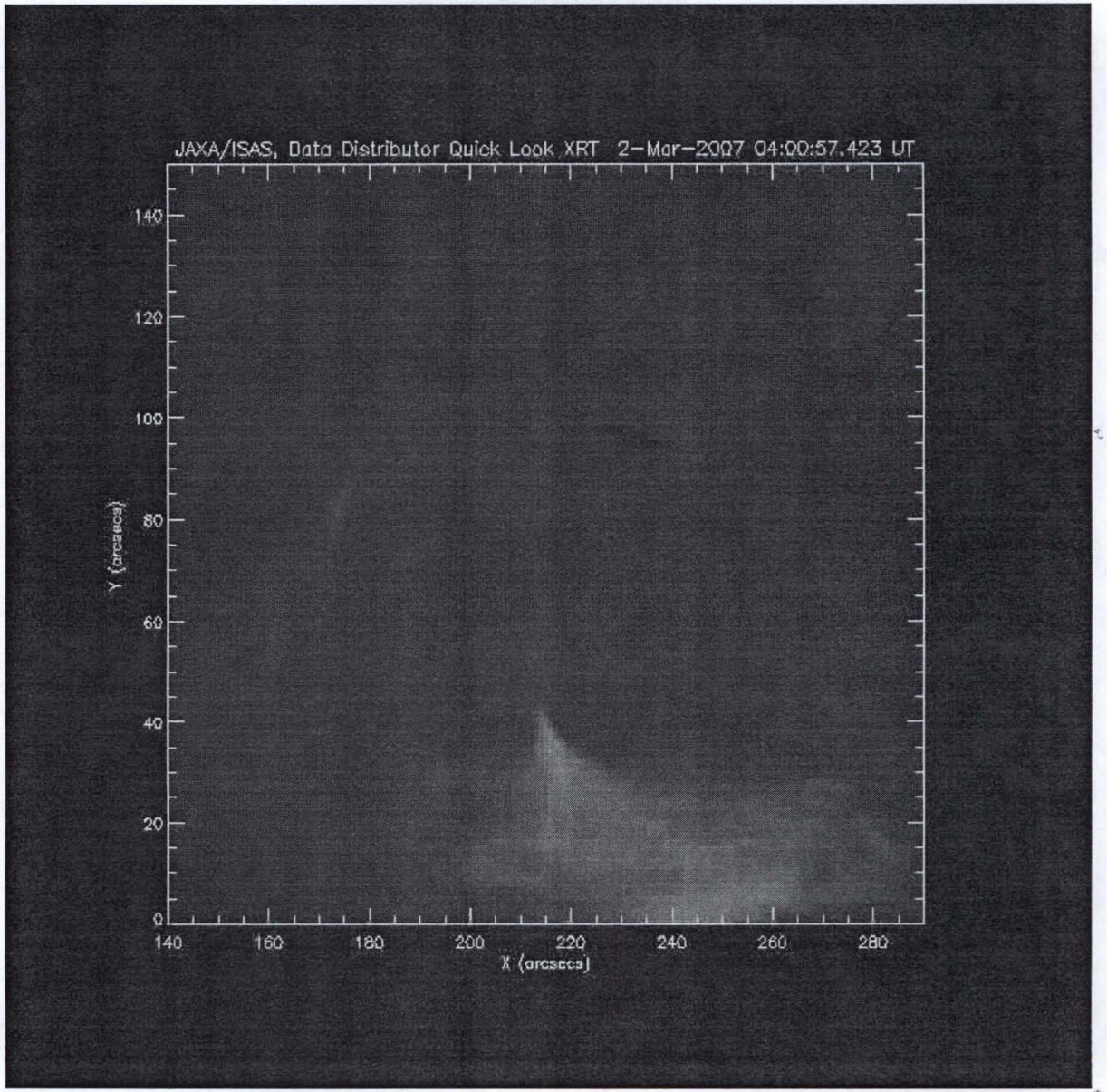
Hinode XRT



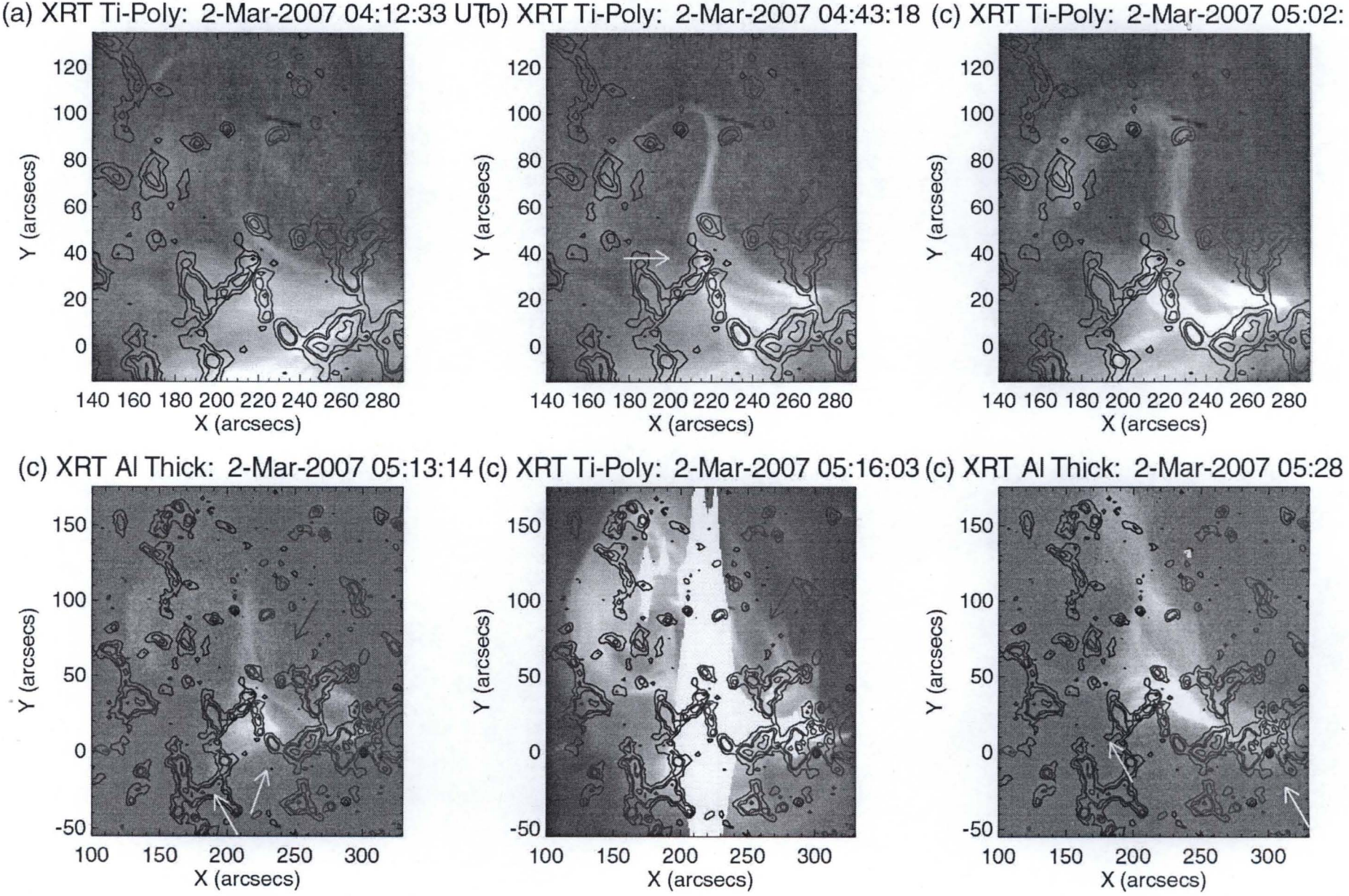
Sterling, Dublin 2007

XRT (blowup)



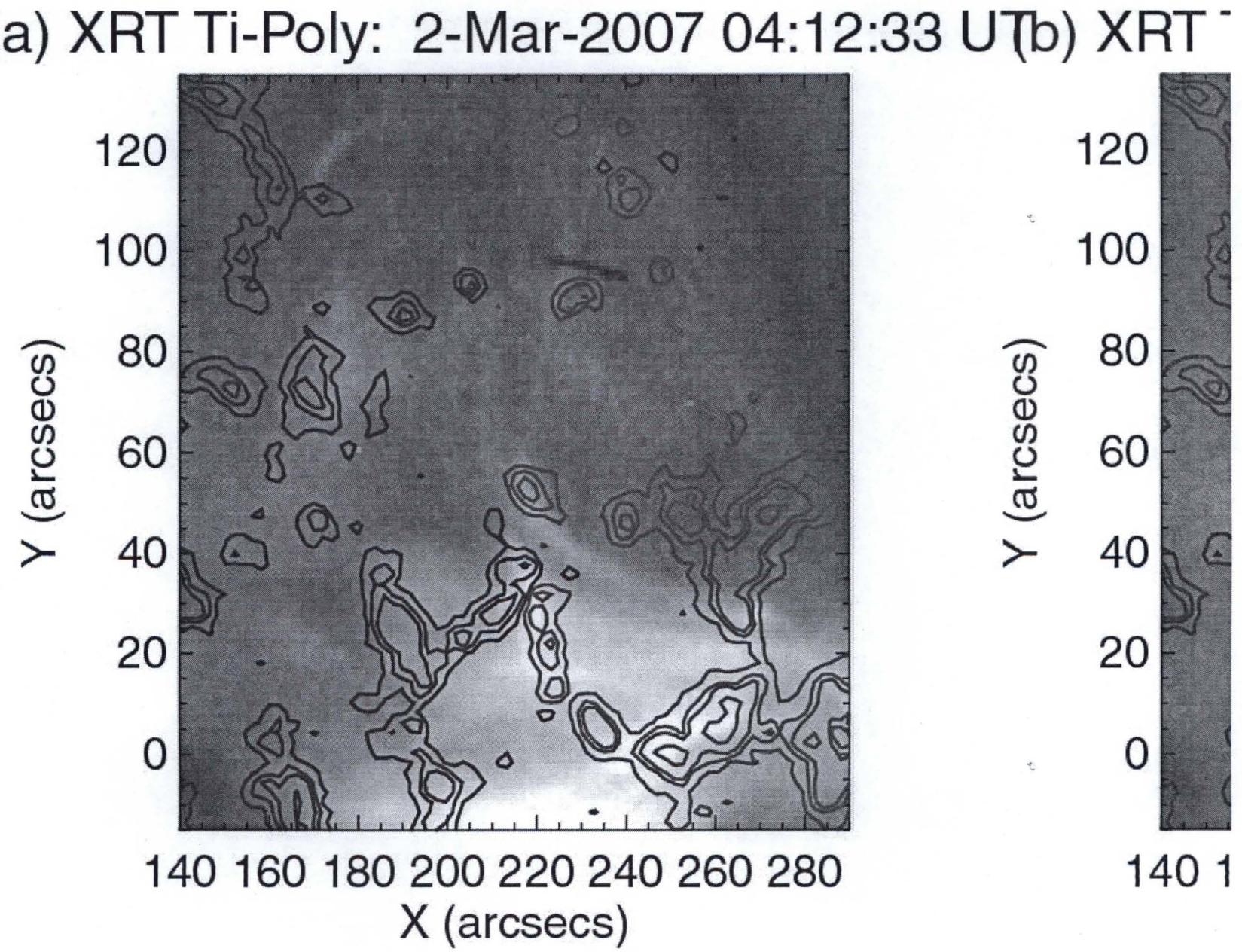
Sterling, Dublin 2007

XRT on MDI



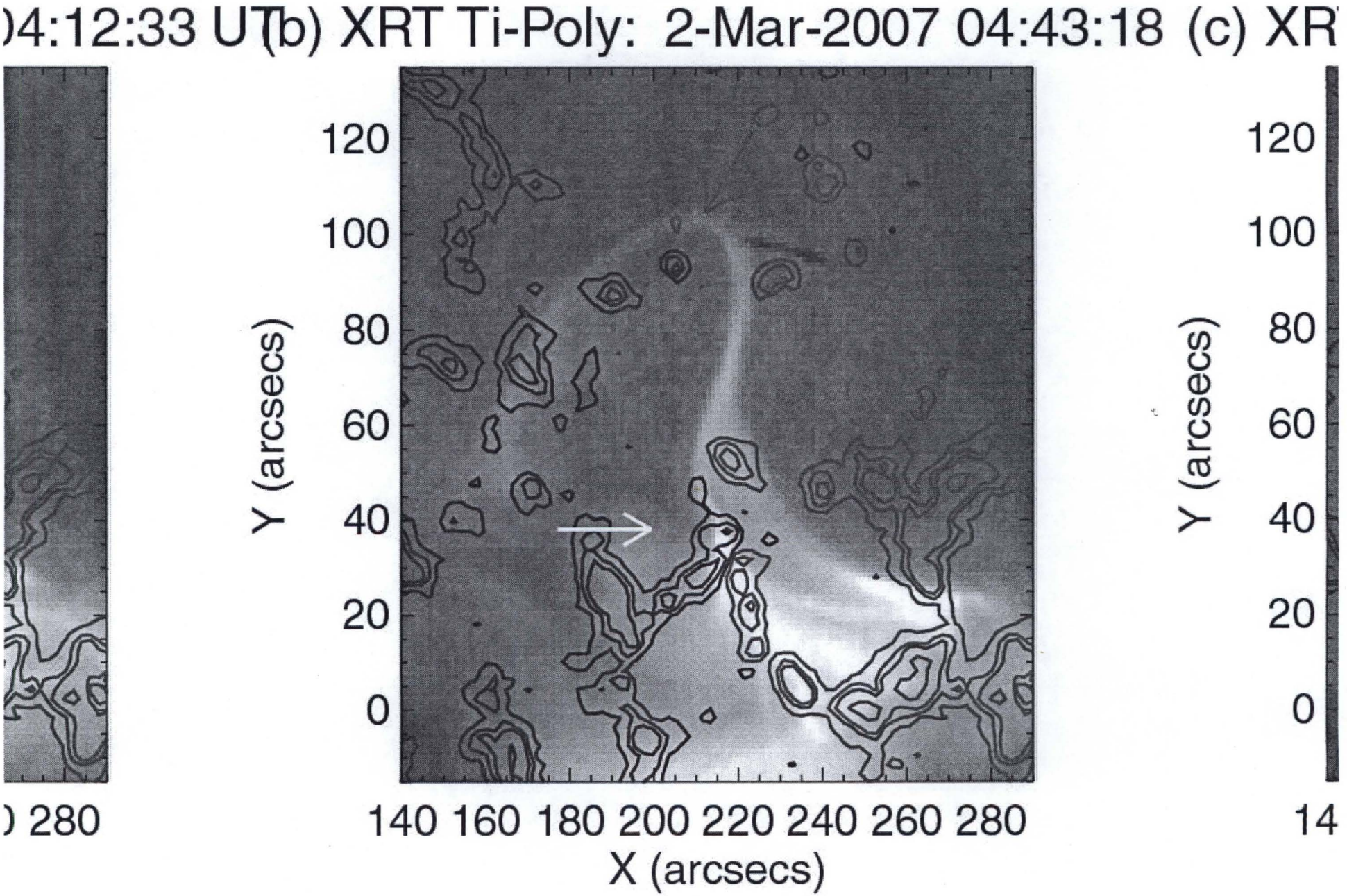
Sterling, Dublin 2007

XRT on MDI



Ste

XRT on MDI


)4:12:33 UT
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120
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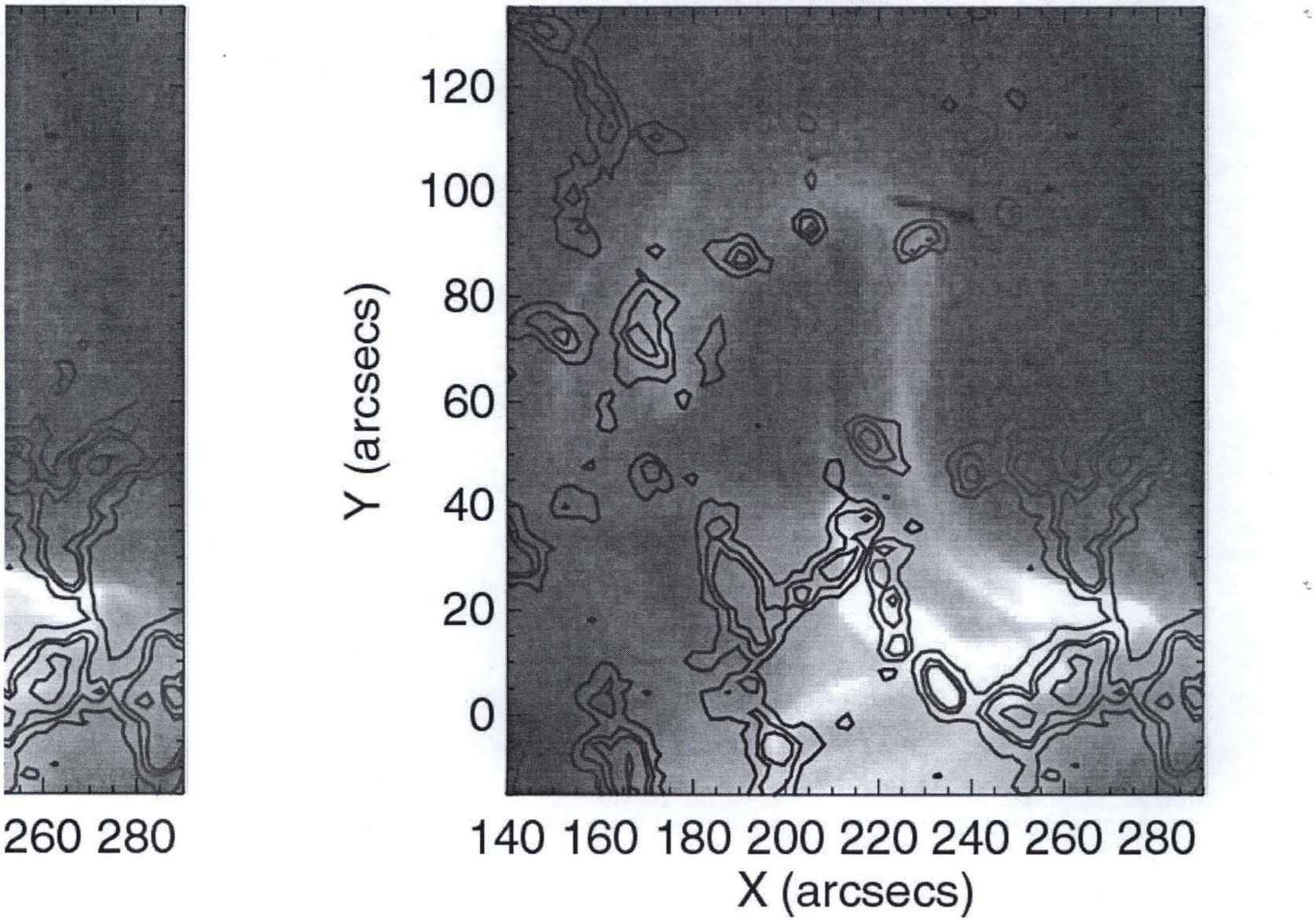
X (arcsecs)

XRT on MDI


)07 04:43:18 (c) XRT Ti-Poly: 2-Mar-2007 05:02:
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Y (arcsecs)
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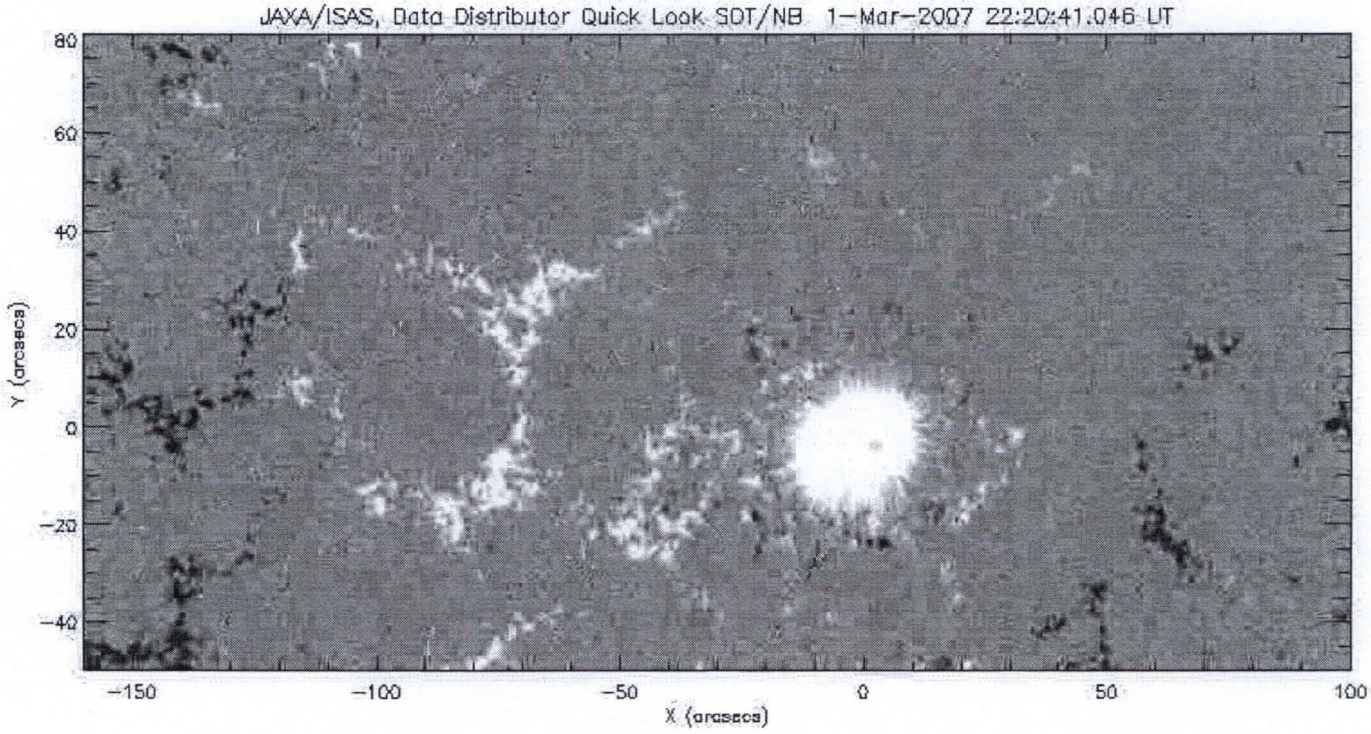
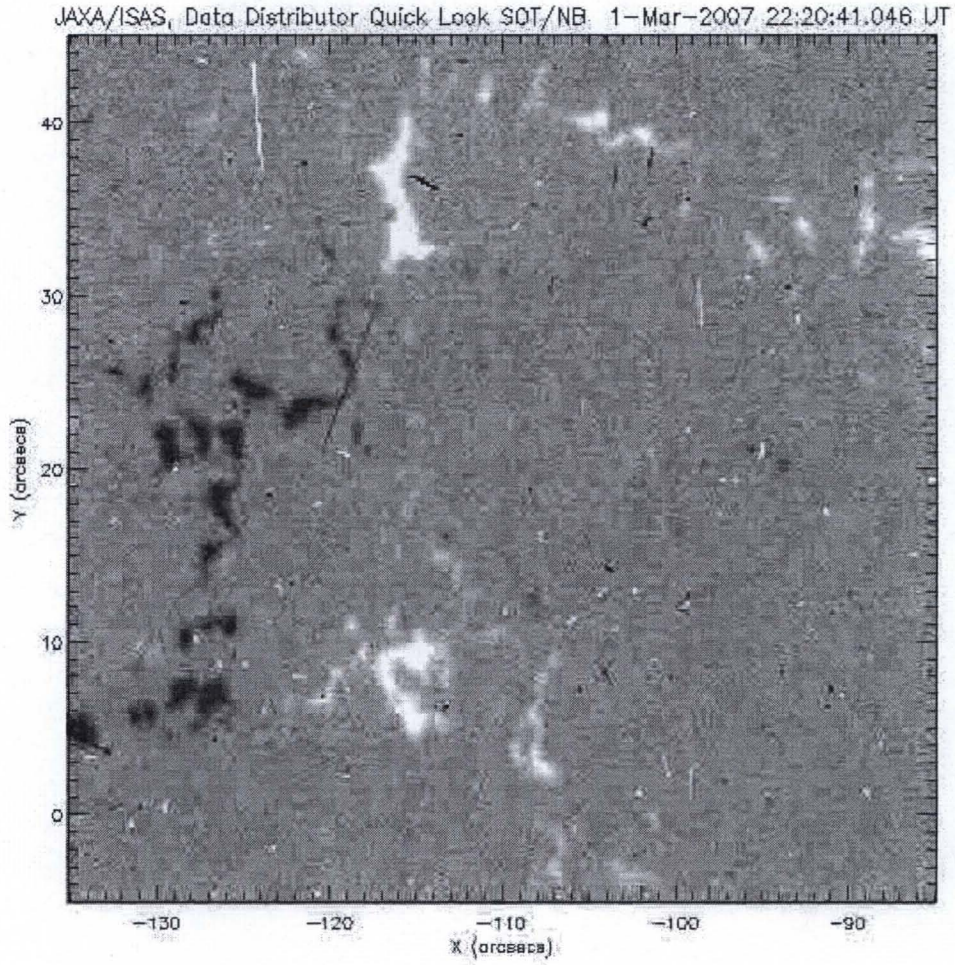
X (arcsecs)

SOT FG V magnetogram



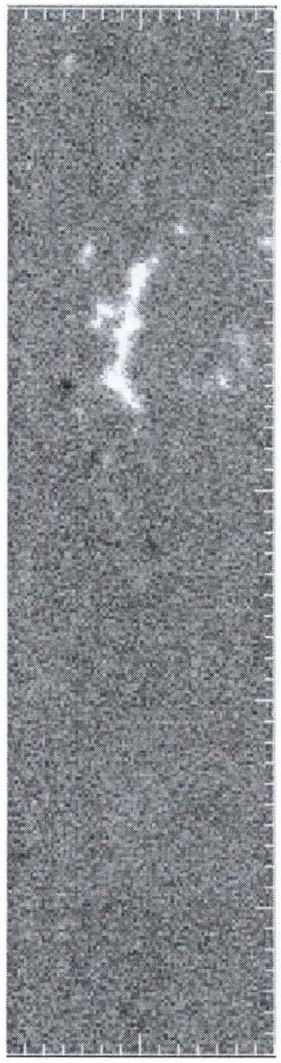
Sterling, Dublin 2007

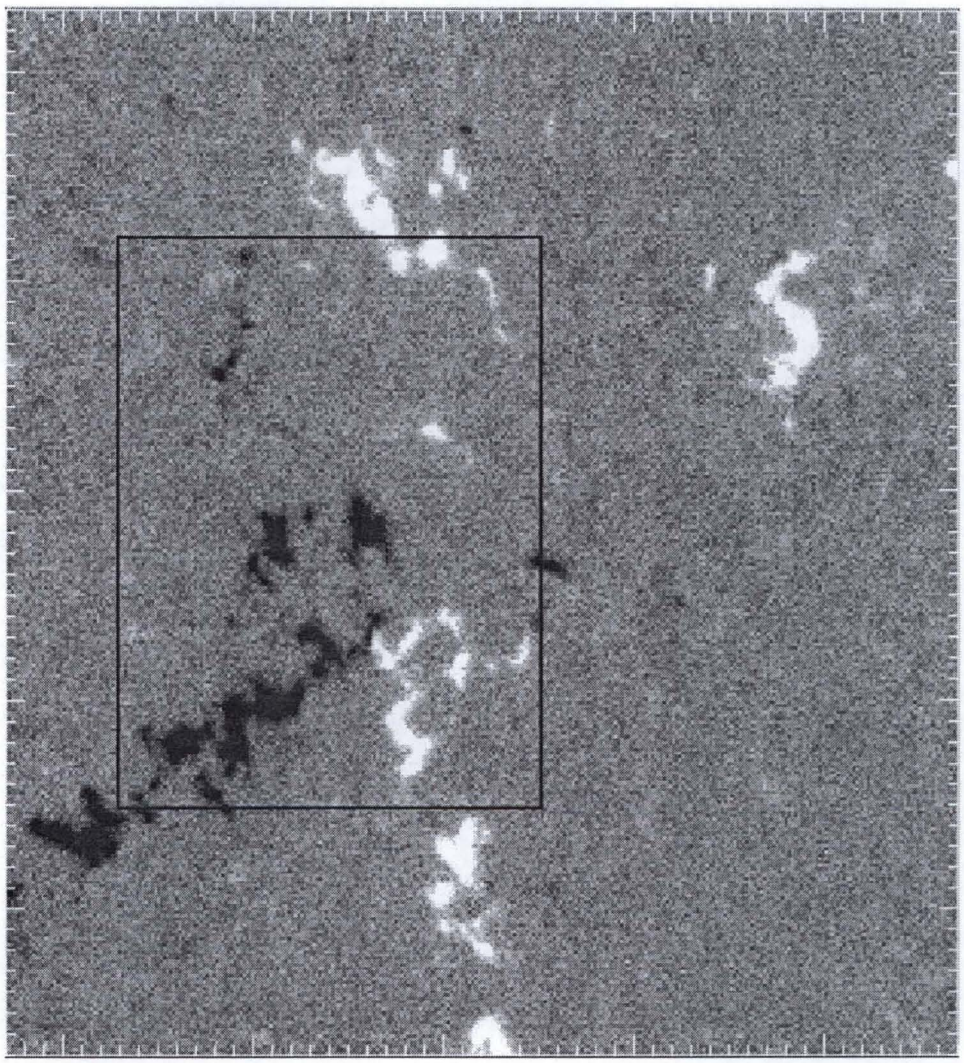
SOT FG/V (blowup)



Sterling, Dublin 2007

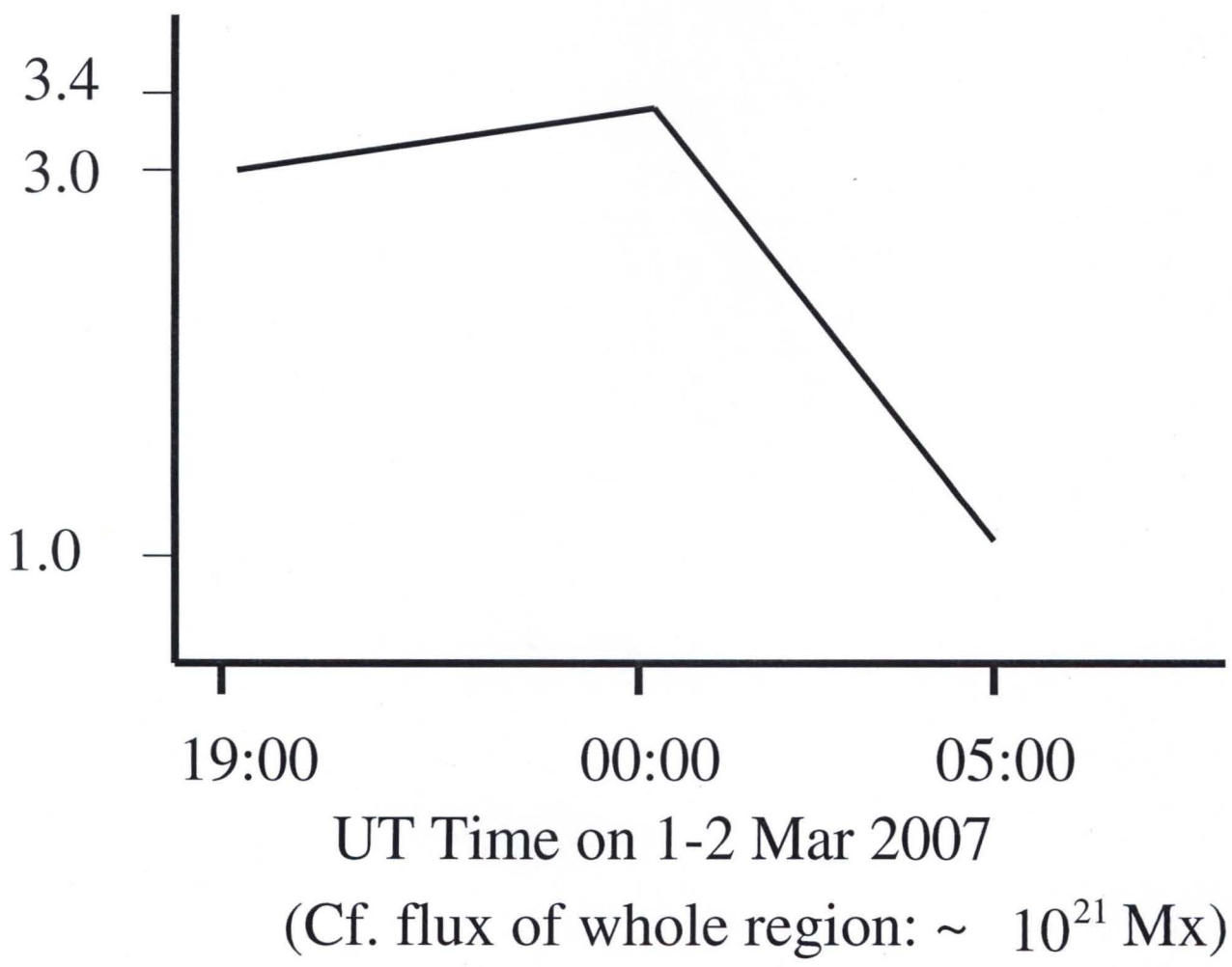
2-Mar-2007 04:54



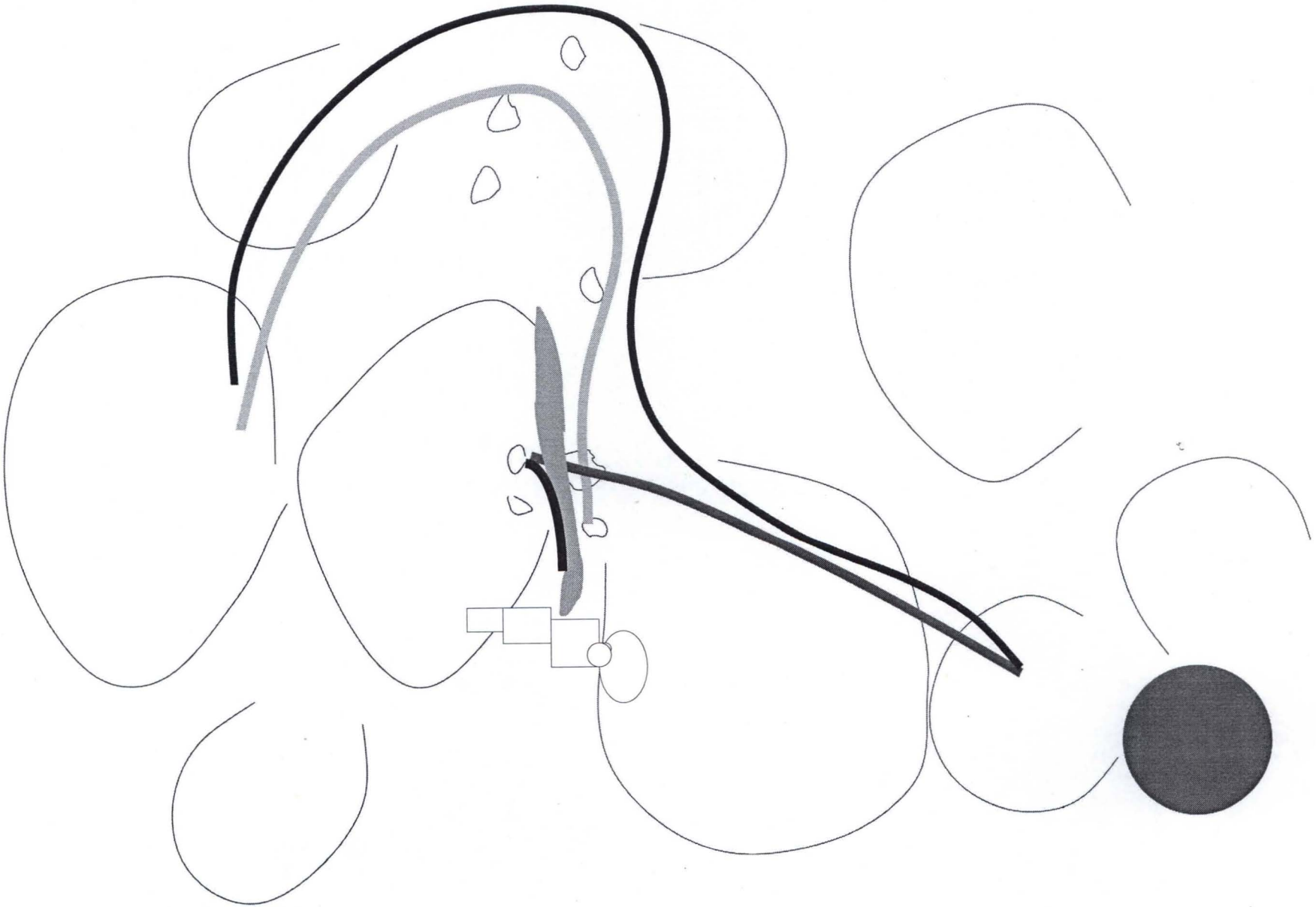


(This is SOT, but use MDI to get flux.)

Sterling, Dublin 2007



Sterling, Dublin 2007



Sterling, Dublin 2007

Discussion

This initial observation from Hinode of a filament eruption supports the idea that flux changes in or near the eruption site are responsible for pre-explosive phase (e.g., slow-rise phase) dynamics.

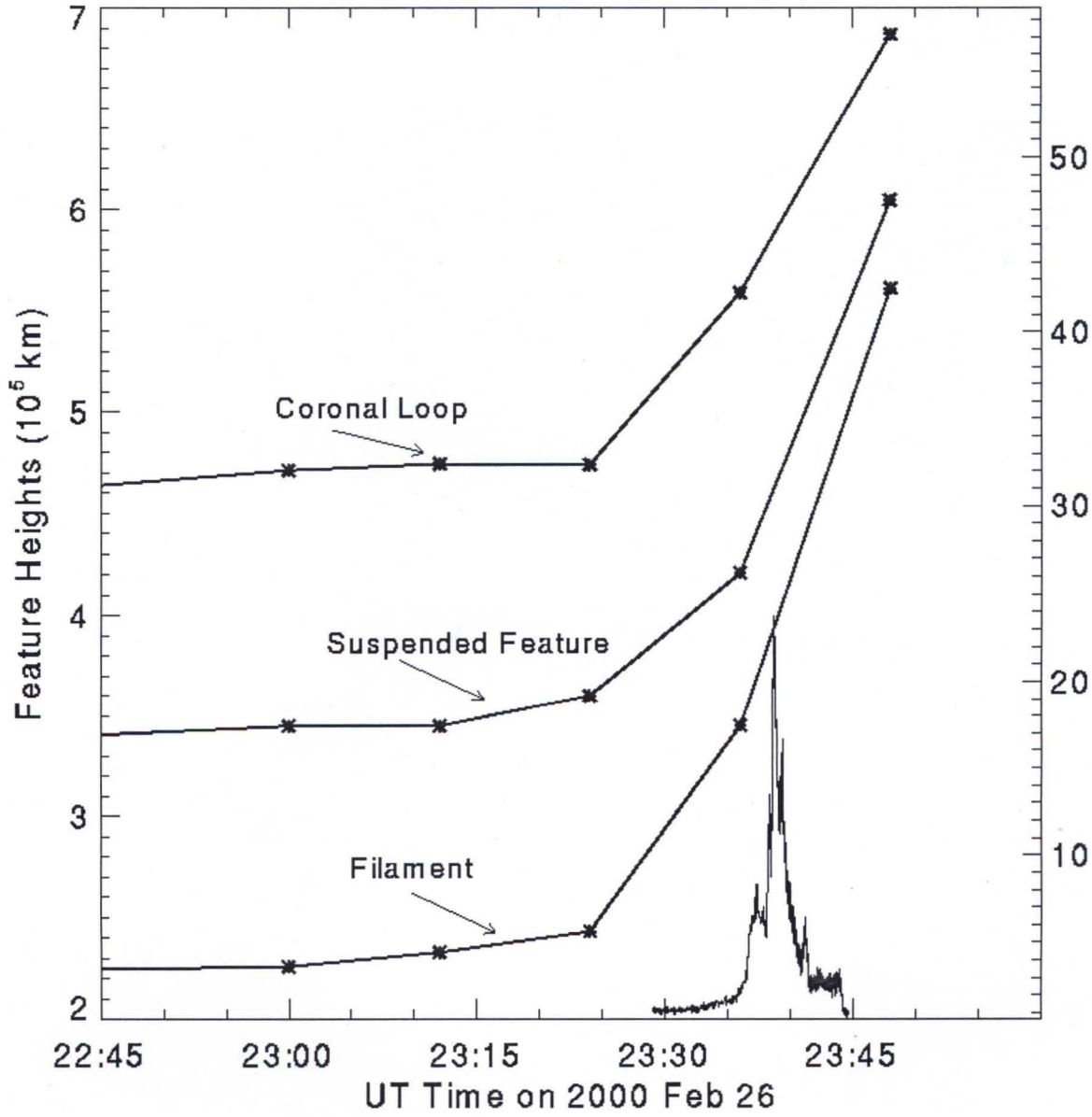
Flux changes = flux emergence and/or flux cancelation (also: tether weakening, slow tether cutting).

(E.g., van Ballegooijen & Martens 1989, Moore & Roumeliotis1992, Rust & Kumar 1996, Lin & Forbes 2000, Feynman &Ruzmaikin 2004, Sterling, Harra & Moore 2007.) (Also Mikic et al. 2007, this meeting.)

Conclusions

- Hinode, STEREO, TRACE observations of 2007 March 2 filament eruption and flare.
- Results still preliminary, but support that pre-eruption (pre-flare) **filament slow-rise phase** is due to early flux changes (in this case: cancelation; slowly driven tether-cutting reconnection).
- During pre-eruption period, $\Delta\Phi \sim 10^{19}$ Mx = ~ 1% of flux of total erupting system.
- No comment (yet!) on what triggers the **fast-rise phase**.

Sterling, Dublin 2007



Sterling, Dublin 2007

Observed Characteristics

- **Sample size**. So far, we have examined about 10 (including 2 AR) events "in detail" (e.g., motions and intensity changes); mapped trajectories of about 25 additional events.
- **Trajectory.** Filament eruptions often undergo two stages: slow and fast (e.g., Tandberg-Hanssen et al. 1980, Bong et al. 2006; cf. Ohyama & Shibata 1997).
- **Slow-rise linearity.** In several events, slow rise is fit better with line than with a polynomial or exponential. (Slow-rise is frequently complex, however; Akiyama & Sterling.)
- **Flaring at start of fast eruption.** Onset of SXR and HXR flaring coincides ``closely'' with start of fast eruption.
- **Breakout signatures.** Occur close to time of start of fast eruption. (Moore & Sterling 2006; Bong et al. 2006)

Observed Characteristics – Cont.

- **Dimmings.** (Discussed by many workers; hard to generalize, e.g., Howard & Harrison 2004.)
  - **Local dimmings.** Intensity dimmings next to and along neutral line begin weakly during slow-rise phase (stretching of field lines), and become strong dimmings at start of fast-rise phase.
  - **Remote dimmings (and brightenings).** In some cases, dimmings and brightenings occur at locations far removed from main neutral line, consistent with breakout-type reconnection.
- **Magnetic cavities.** These show that filaments belong to a more extended magnetic environment; interaction with overlying fields can lead to remote brightenings/dimmings. (Cf. Gibson et al. 2006.)

Some Theories for Eruption Onset:

- Tether cutting.
- Breakout model.
- MHD Instability.

(Generally, this applies to "fast eruption" onset, although slow rise might be part of the process.)

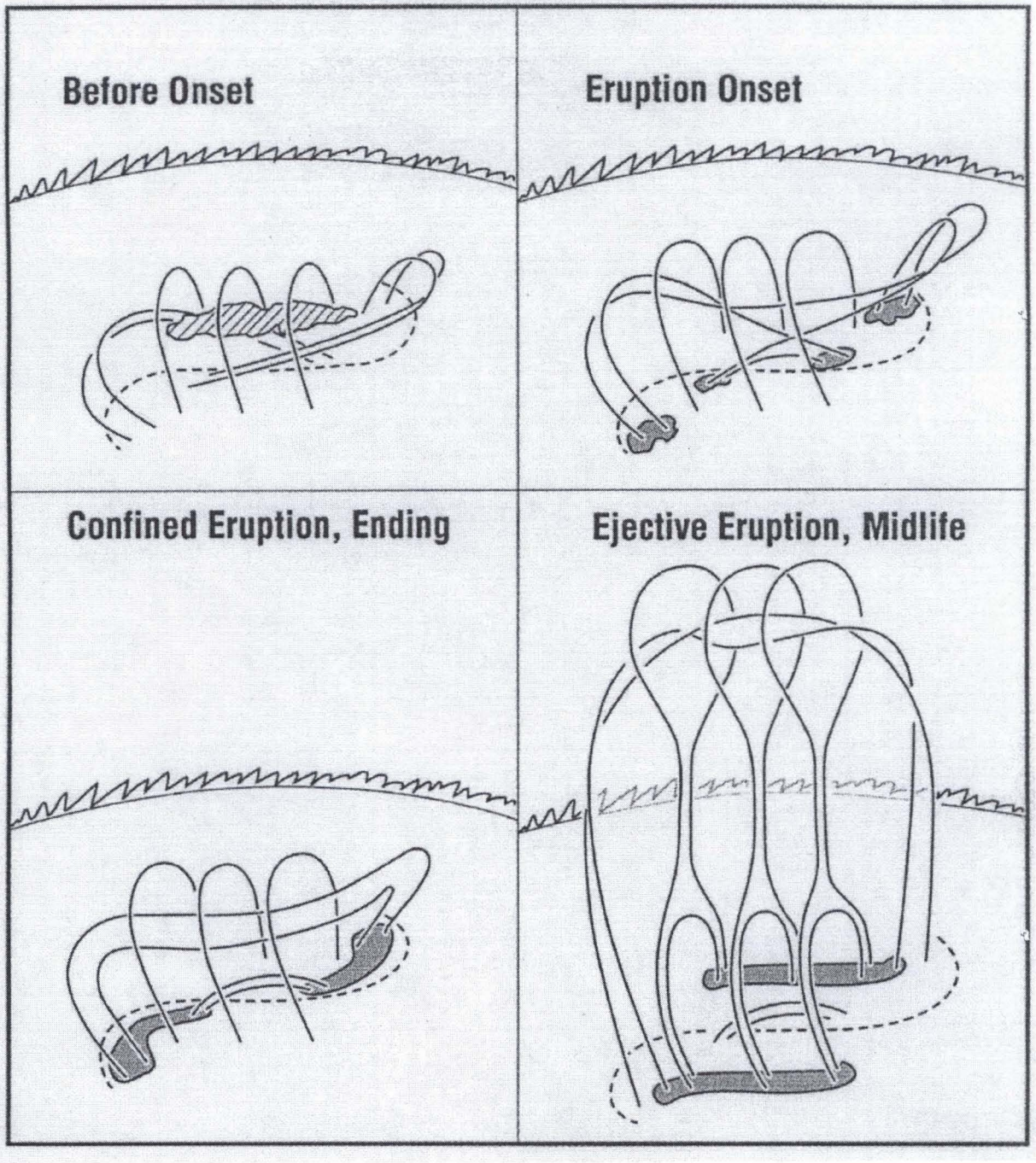
These theories are testable (at least to within some limits) by our observations.

Some Theories for Eruption Onset:

- Tether cutting. Moore & Labonte (1980); Sturrock (1989); Moore et al. (1997; 2001). (Also Chen & Shibata 2000 and Lin et al. 2001.)
  - ➢ Fundamentally bipolar.
  - ➢ Energy release via reconnection deep inside the "core field."

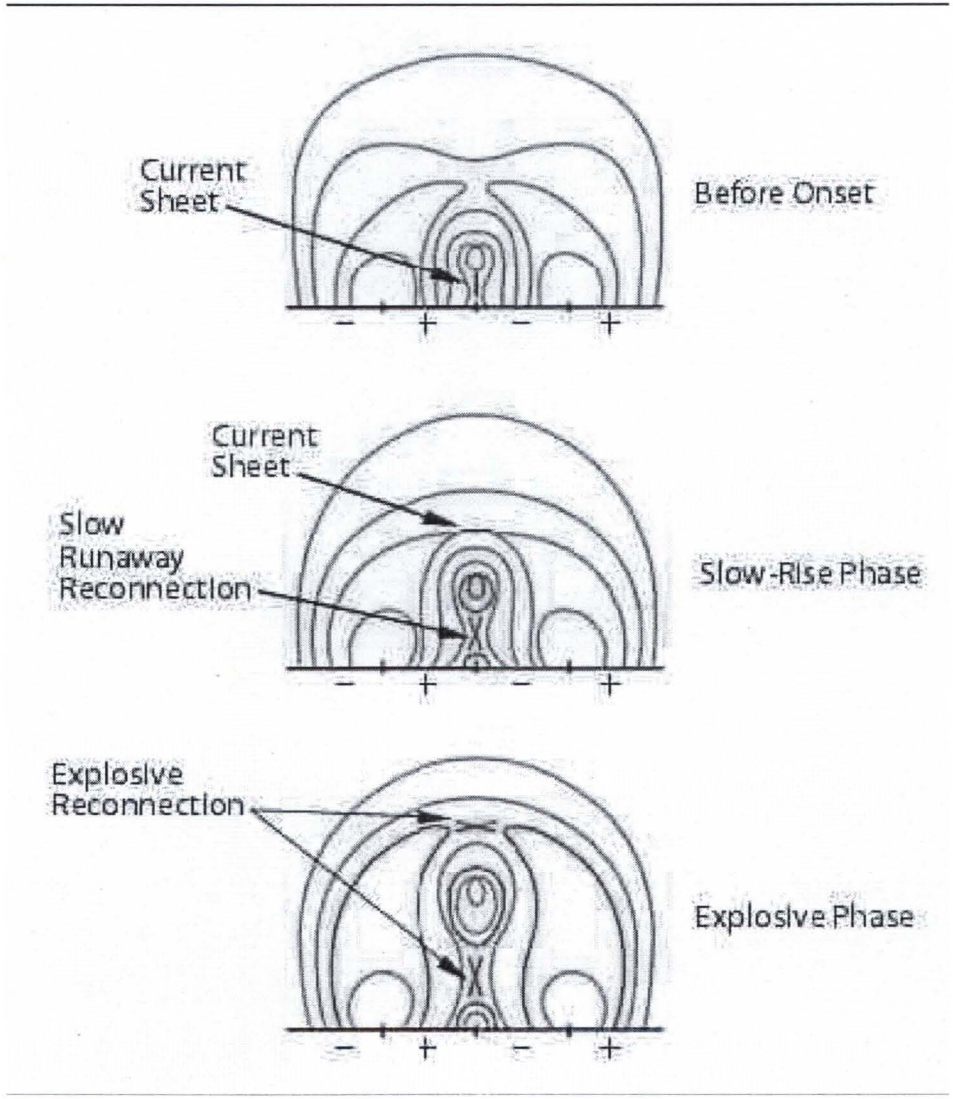
- Breakout model. Antiochos (1998); Antiochos et al. (1999).
  - ➢ Fundamentally multi-polar, with bipole core fields and restraining overlying fields.
  - ➢ Earliest energy release via slow reconnection at interface.

- MHD Instability. Sturrock et al (2001); Rust & LaBonte (2005)
  - ➢ Rapid rise prior to reconnection onset.



(Moore et al. 2001)

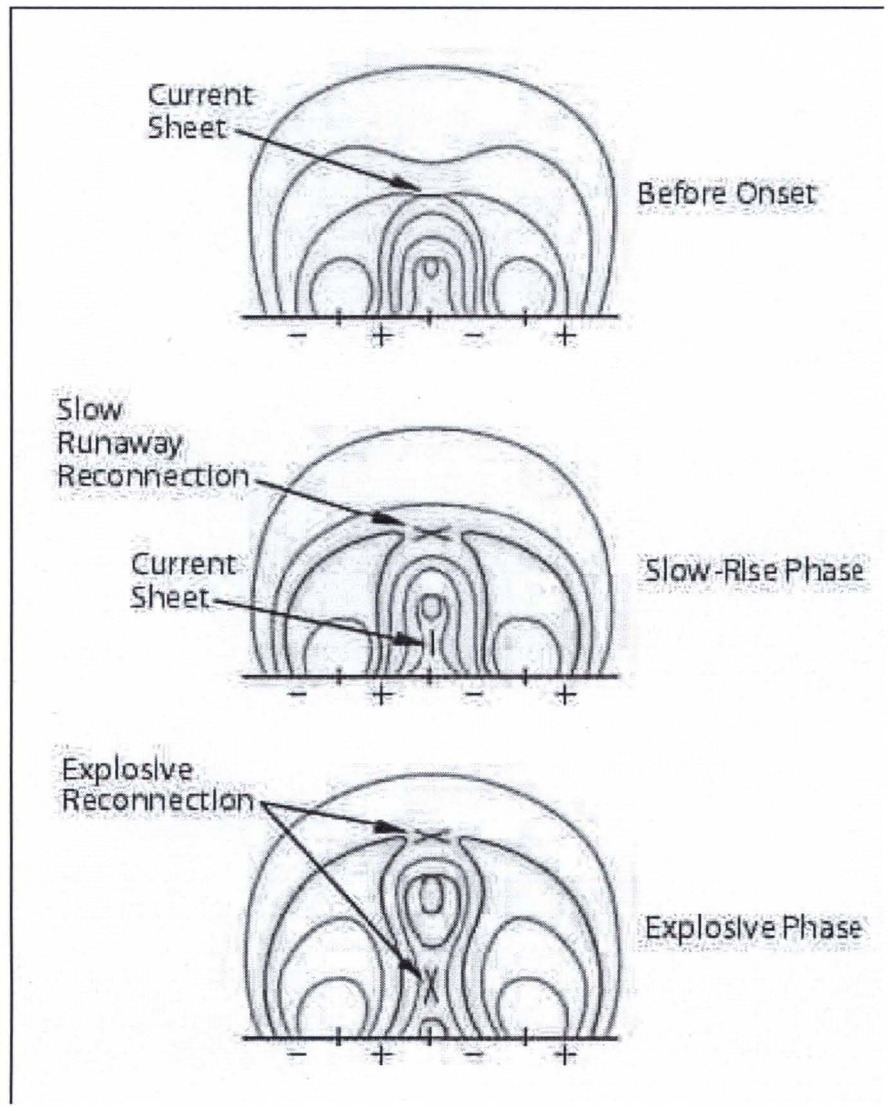
Runaway Tether-Cutting Reconnection



Sterling, Dublin 2007

(Moore & Sterling 2006)

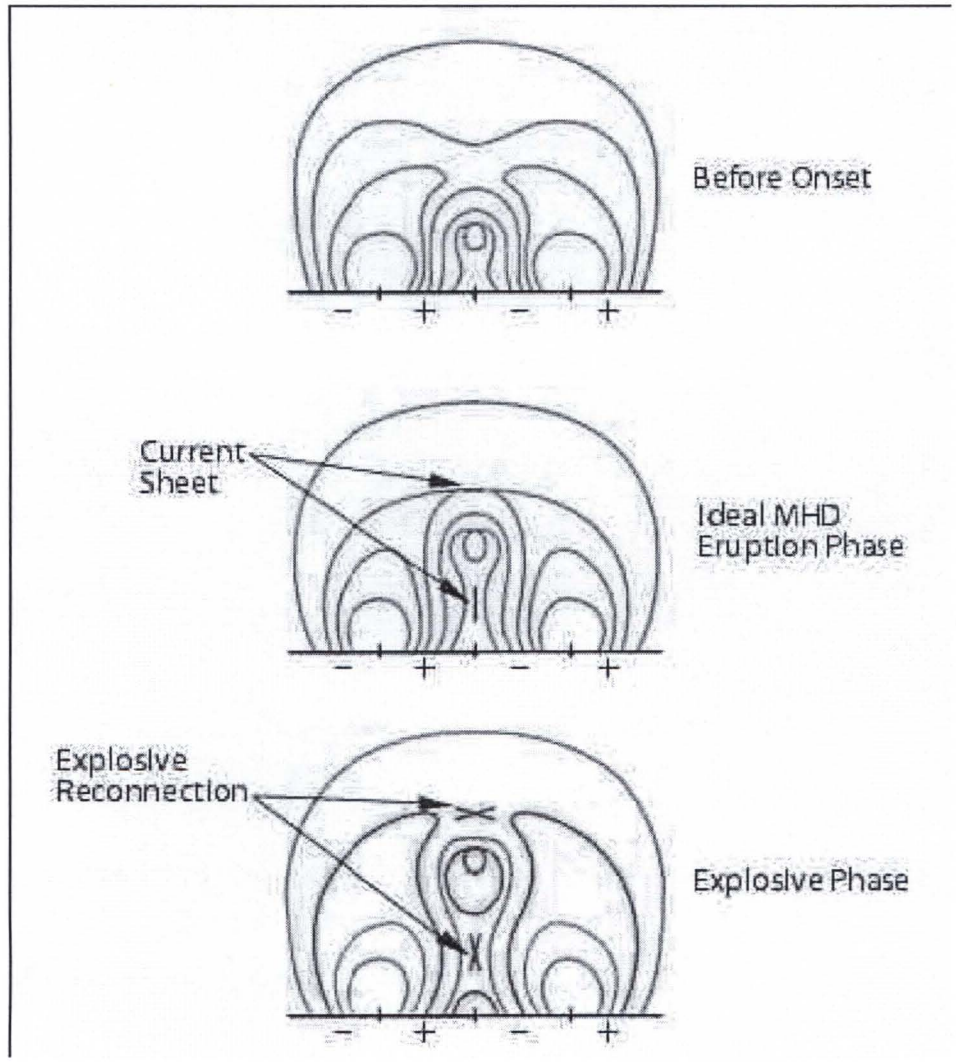
Breakout Reconnection



Sterling, Dublin 2007

Moore & Sterling 2006

Ideal MHD Instability



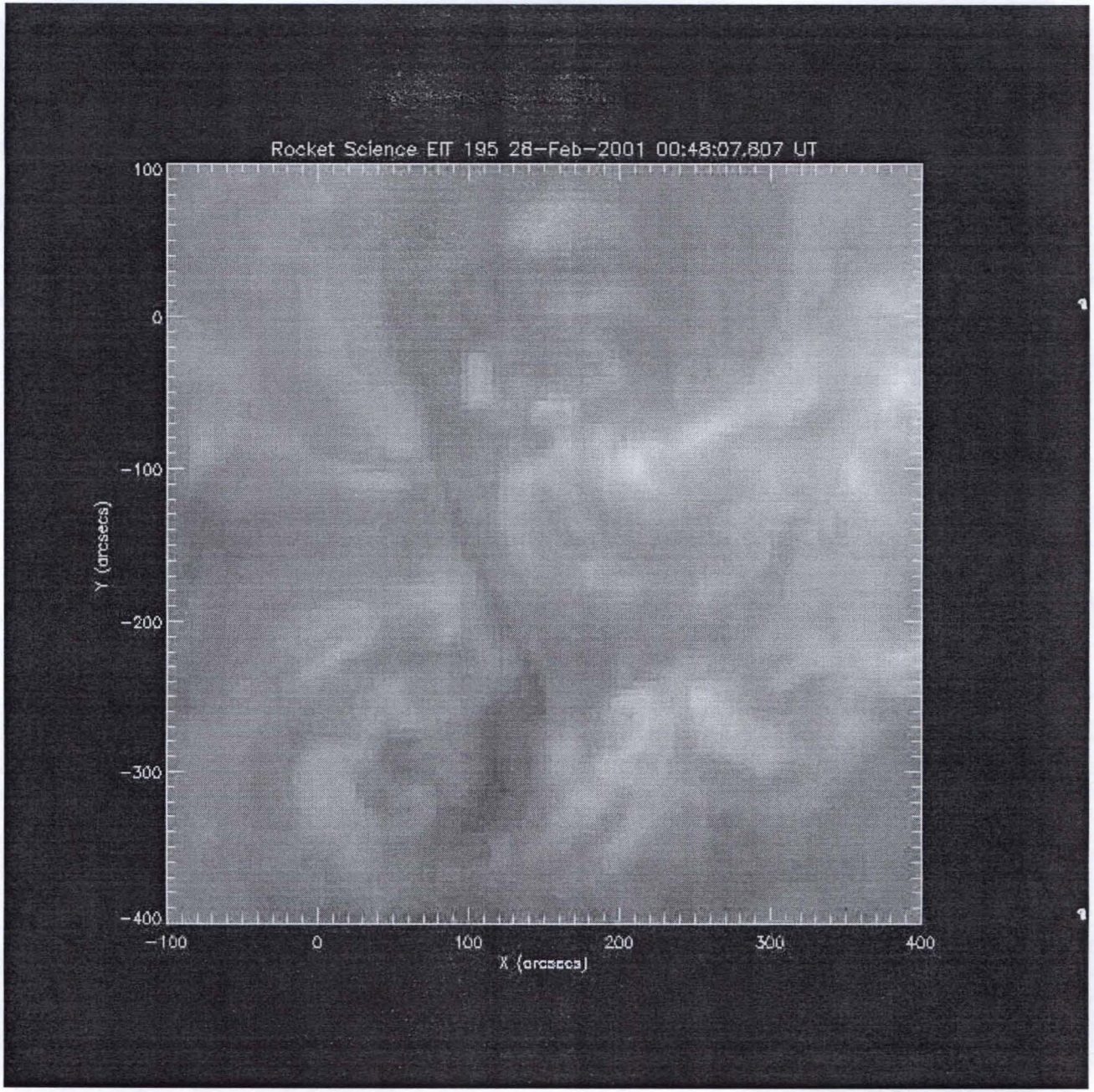
Sterling, Dublin 2007

Moore & Sterling 2006

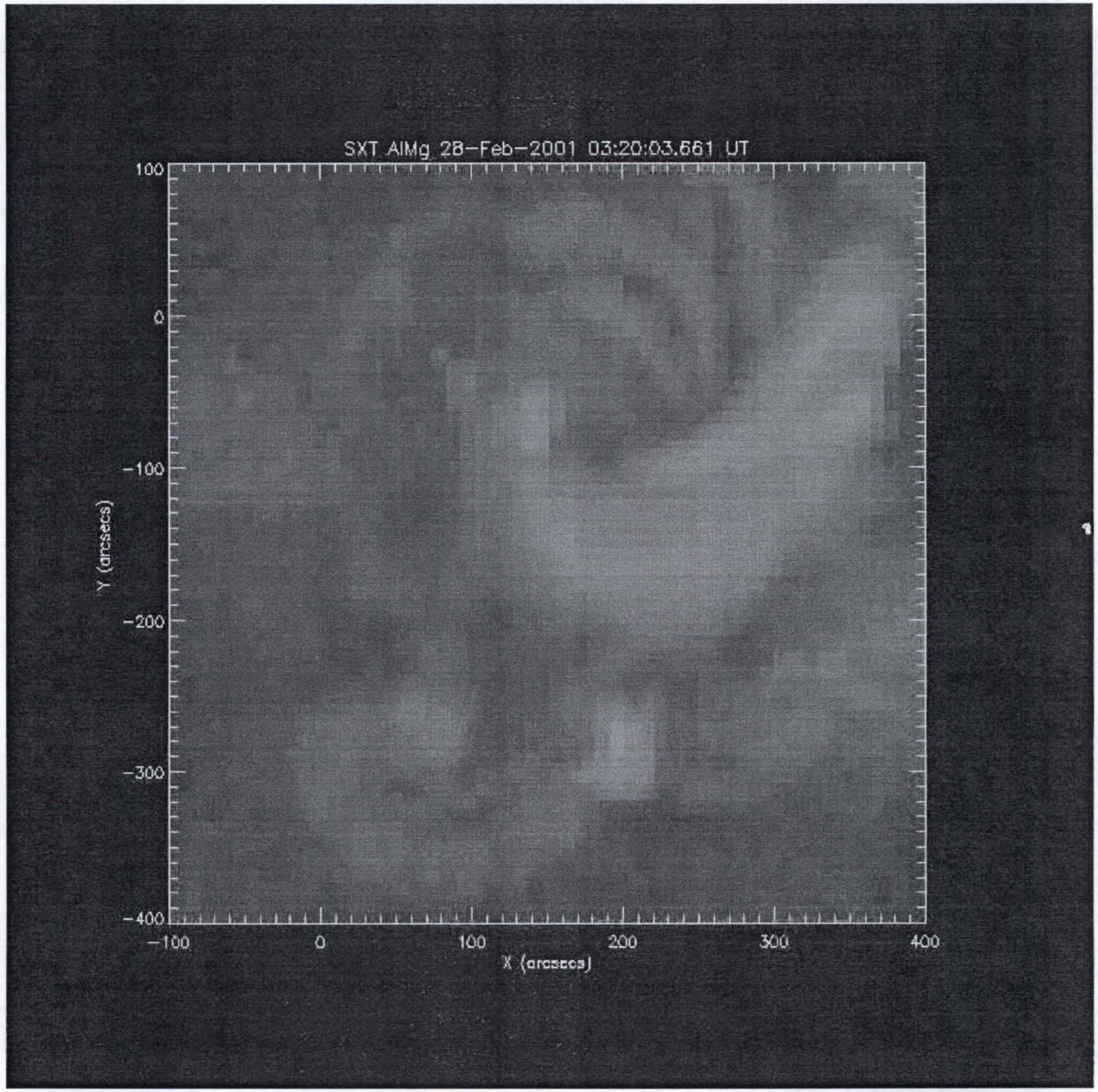
What Causes the Slow Rise?

All our events have a slow-rise phase (although characteristics differ). What's the cause?

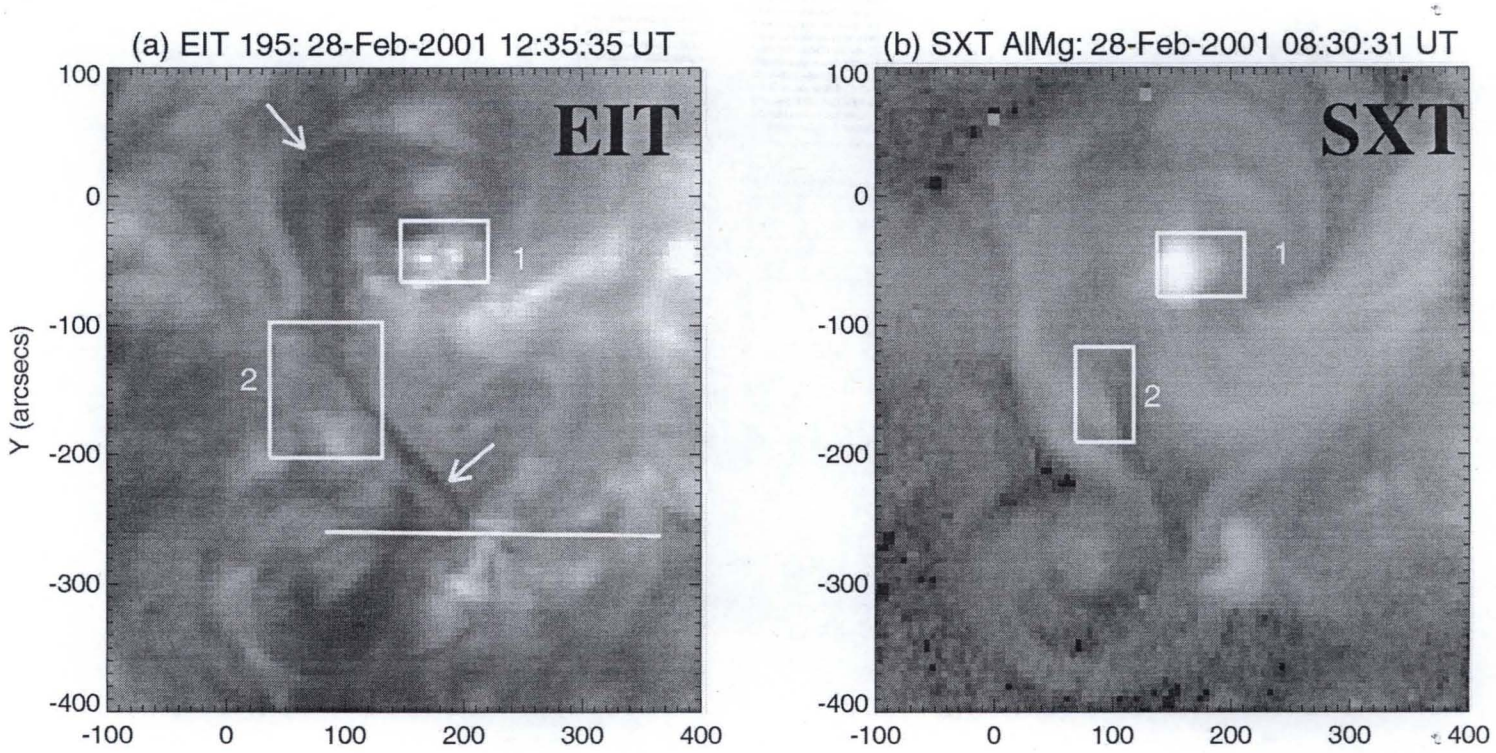
Consider quiet-region filament eruption of 28 Feb 2001 (Sterling, Harra, & Moore 2007)



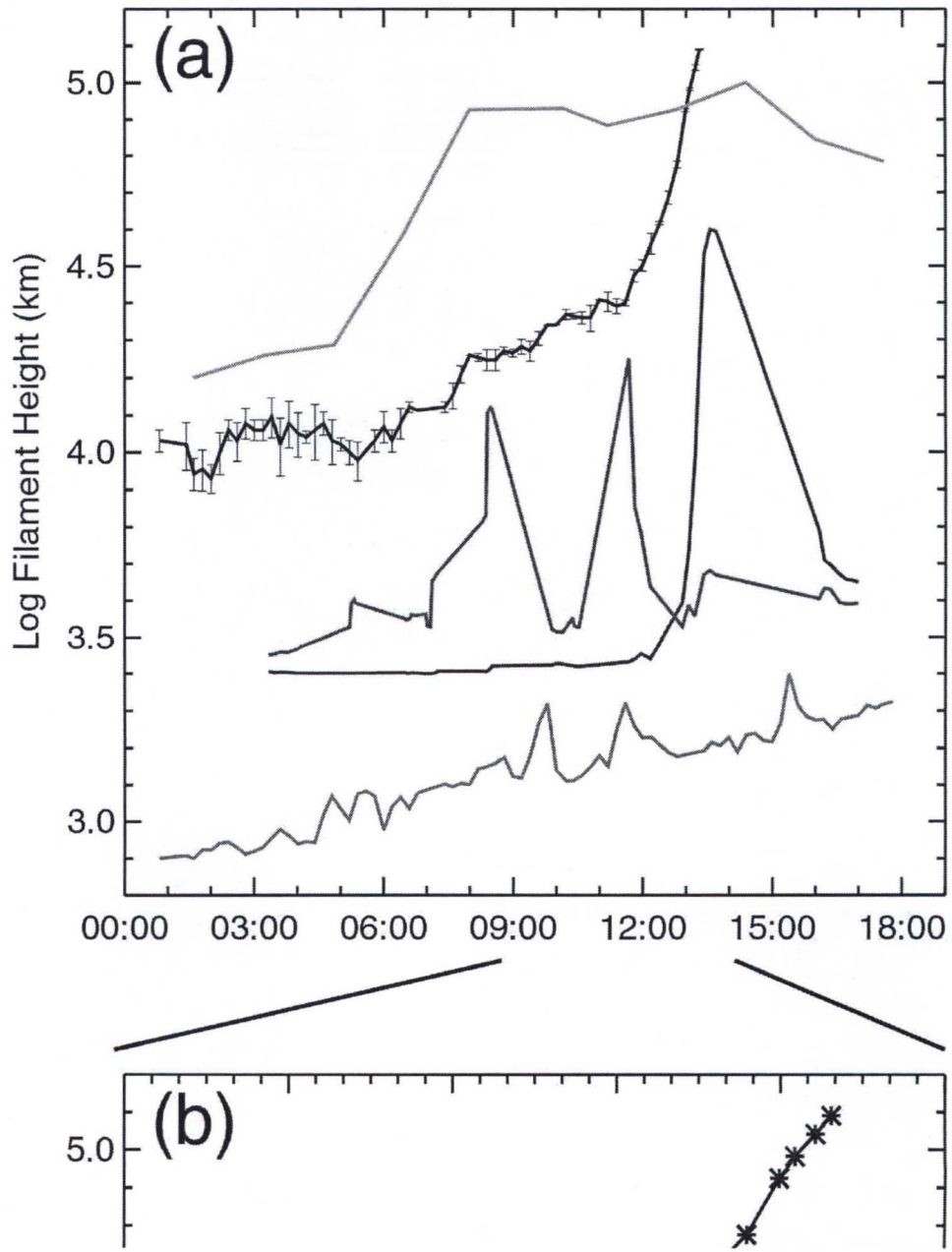
Sterling, Dublin 2007



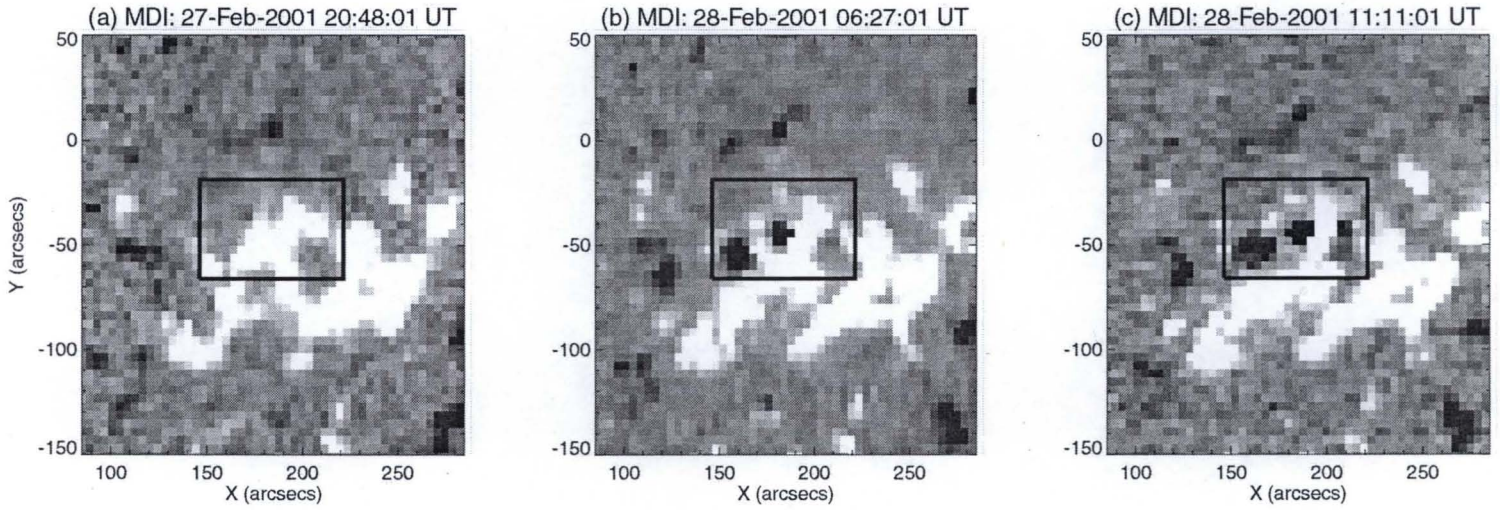
Sterling, Dublin 2007



Sterling, Harra, & Moore (2007)

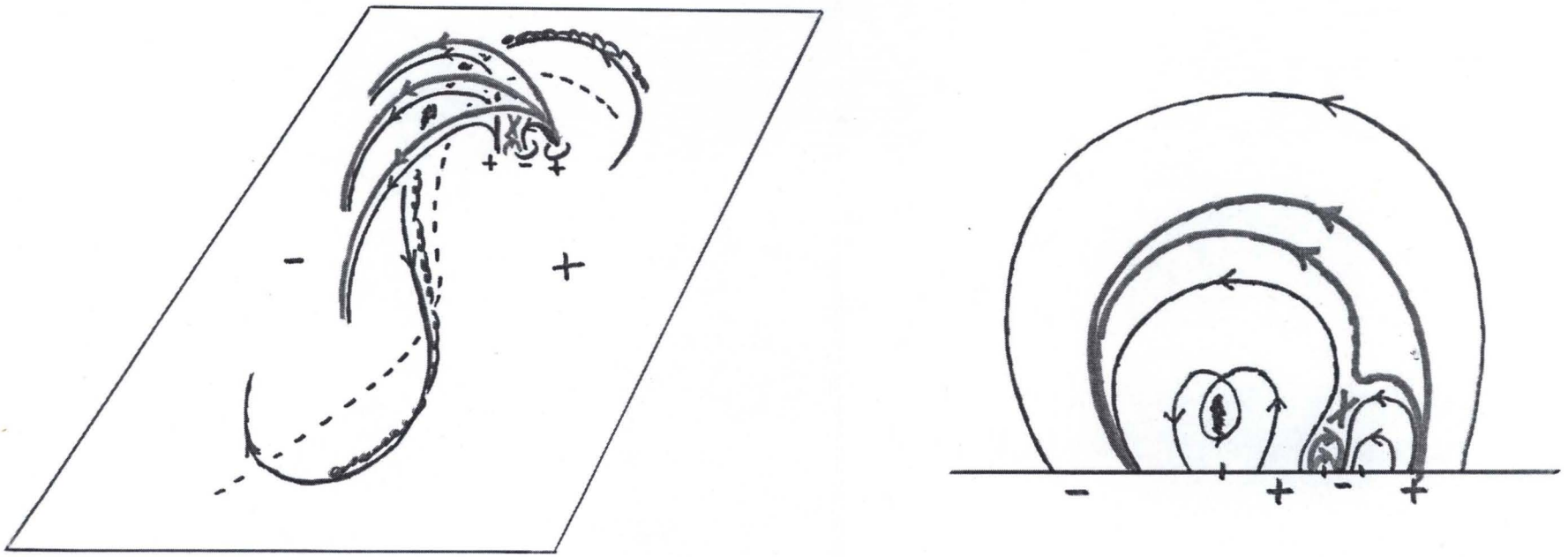


Sterling, Dublin 2007



Cf. Feynman & Ruzmaikin (2004) (also, e.g., Rust 1976, Heyvaerts et al. 1977, and many others).

Slow-rise phase: Tether-Weakening Reconnection?



Sterling, Harra, Moore (2007)

Some Theories for Eruption Onset:

- **Tether cutting. Moore & Labonte (1980); Sturrock (1989); Moore et al. (1997; 2001). (Also Chen & Shibata 2000 and Lin et al. 2001.)**
  - **Fundamentally bipolar.**
  - **Energy release via reconnection deep inside the "core field."**

- Breakout model. Antiochos (1998); Antiochos et al. (1999).
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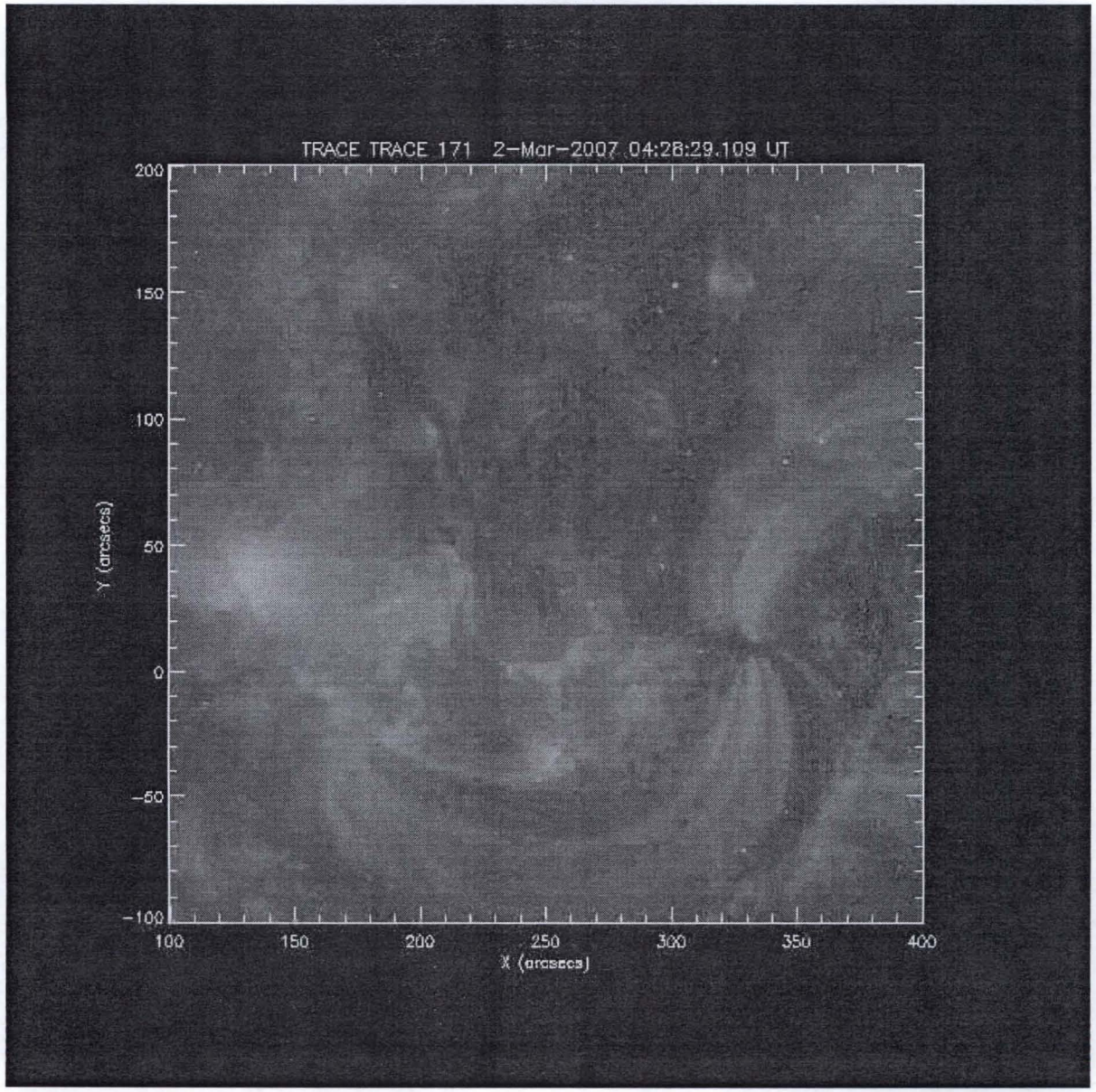
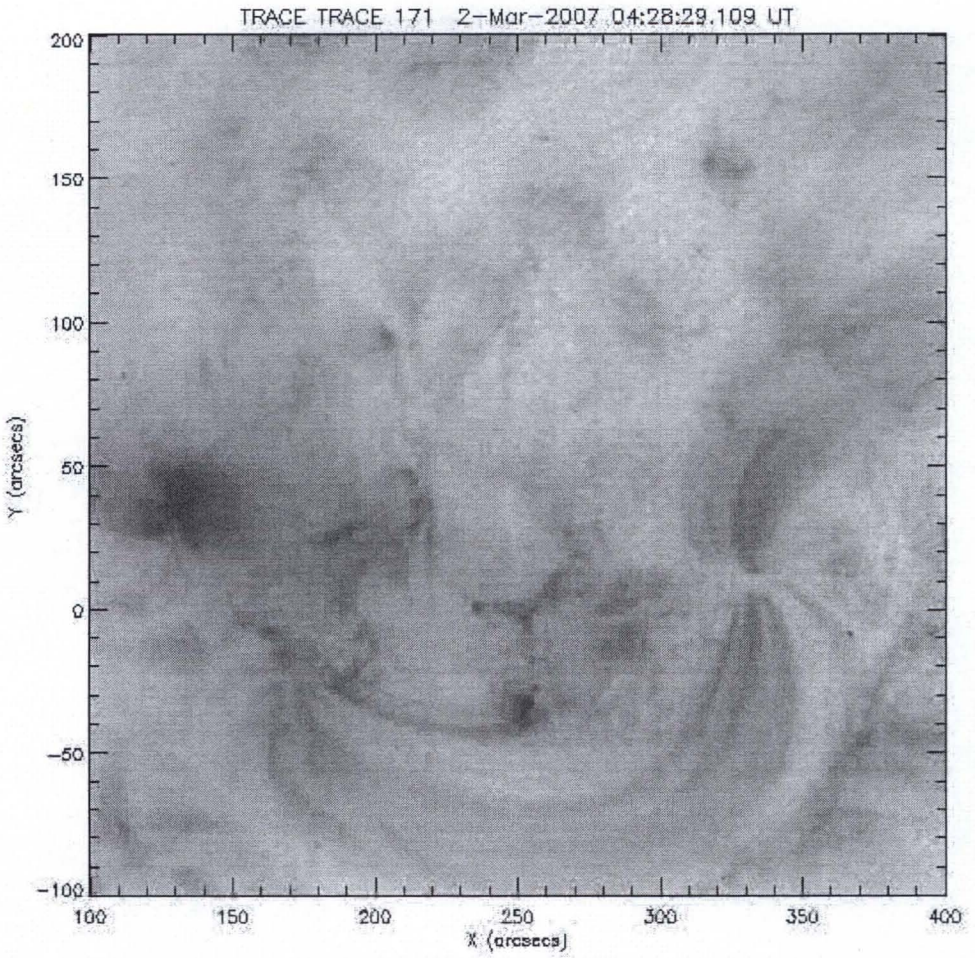
TRACE



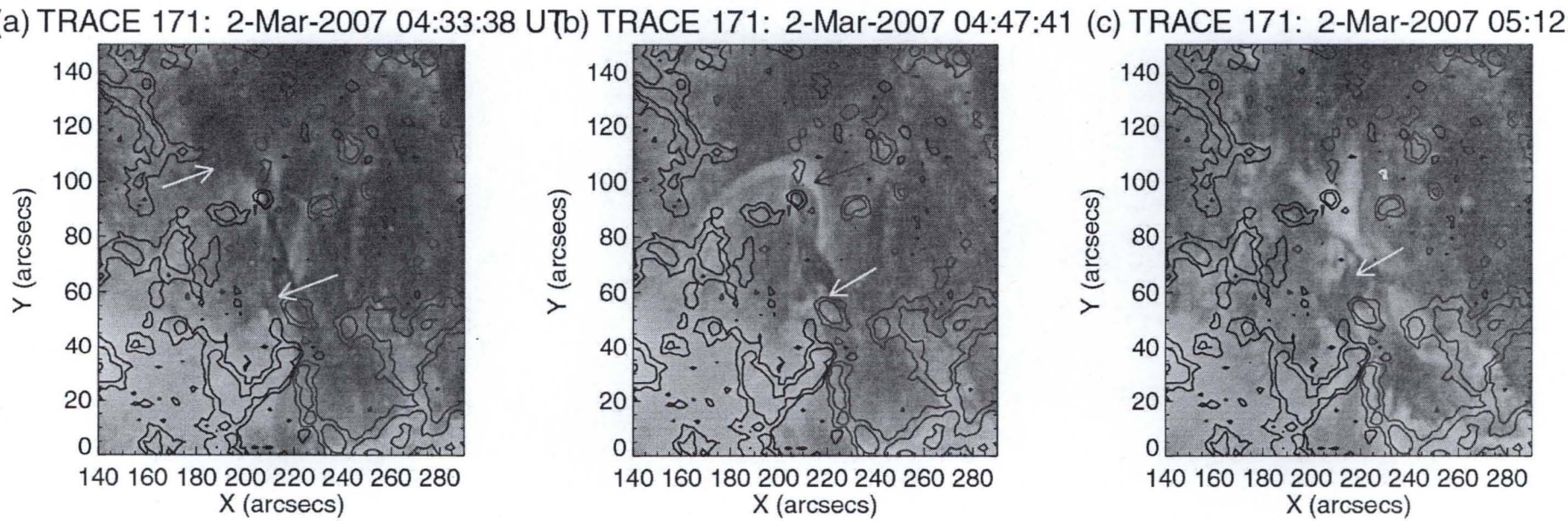
Sterling, Dublin 2007

TRACE (over)



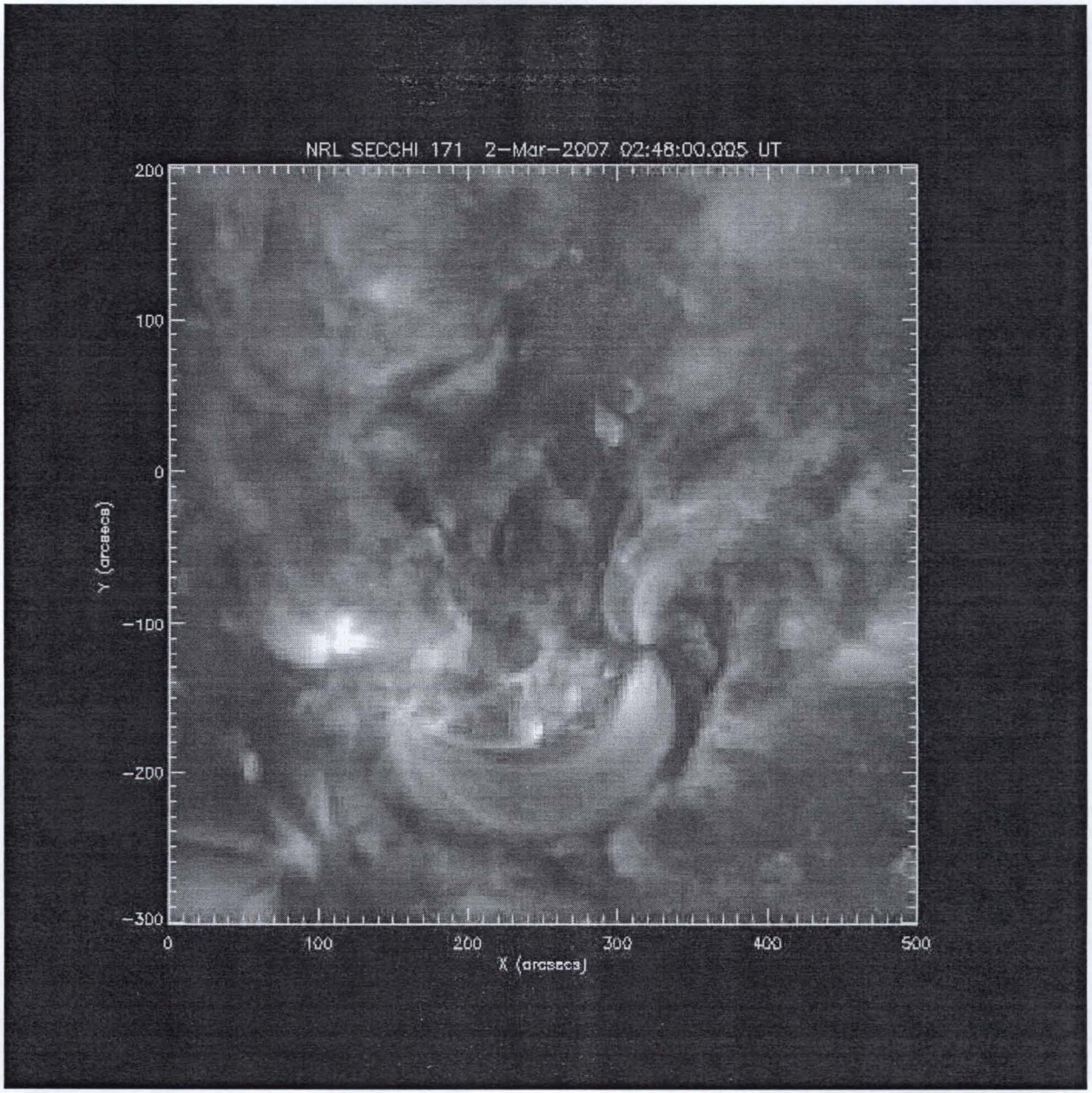
Sterling, Dublin 2007

TRACE on MDI



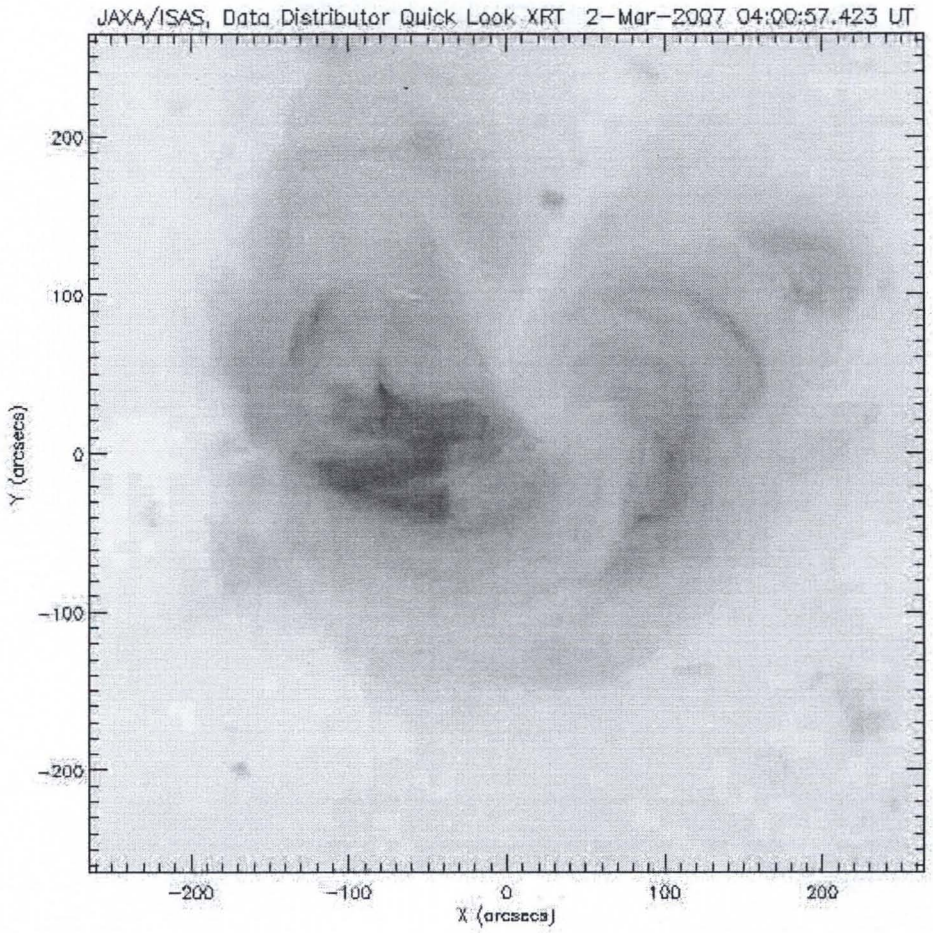
Sterling, Dublin 2007

STEREO 171



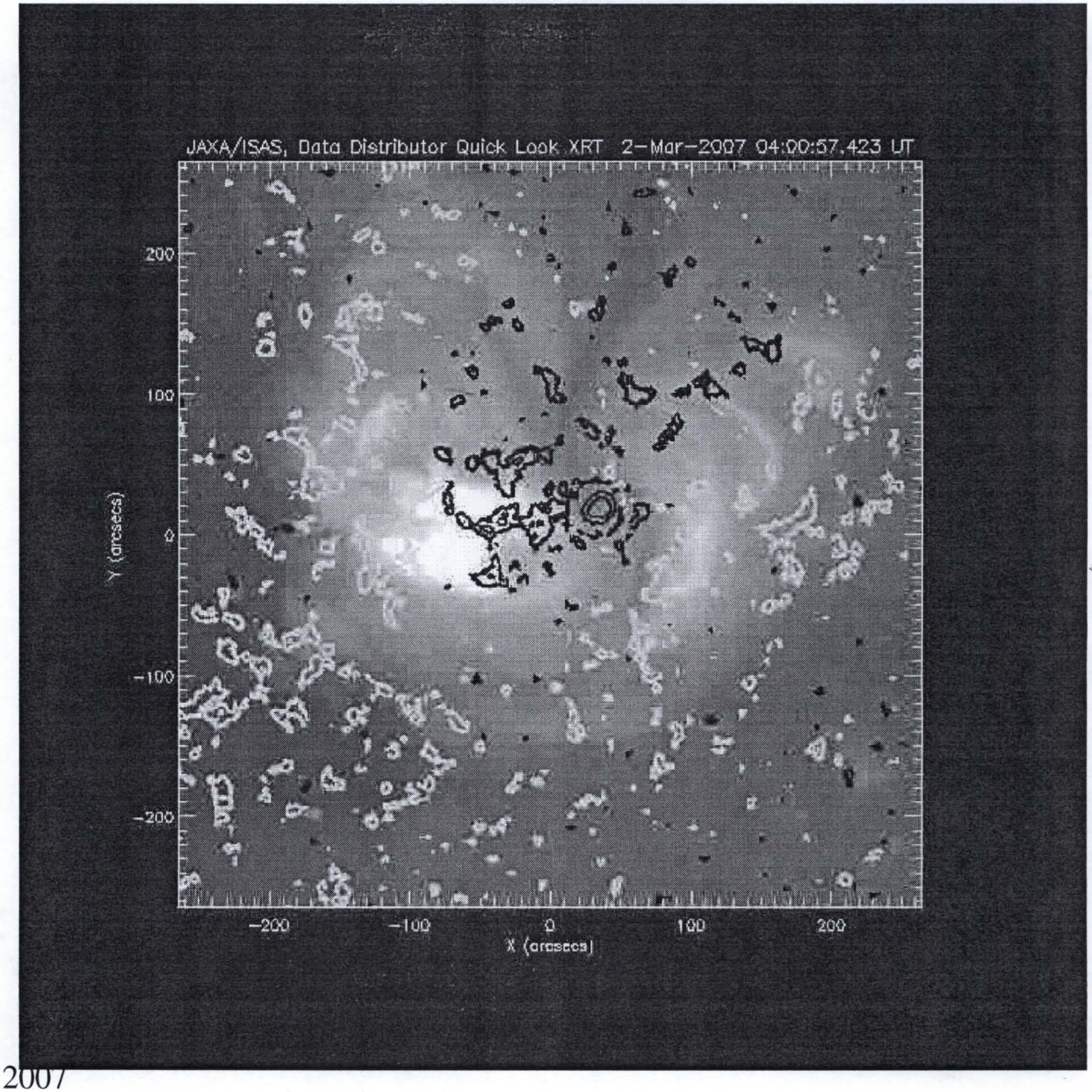
Sterling, Dublin 2007

XRT (over)



Sterling, Dublin 2007

XRT on MDI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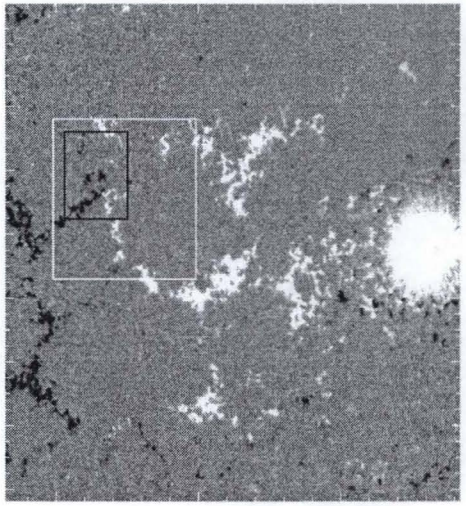
SOT FG/V

2-Mar-2007 05:54



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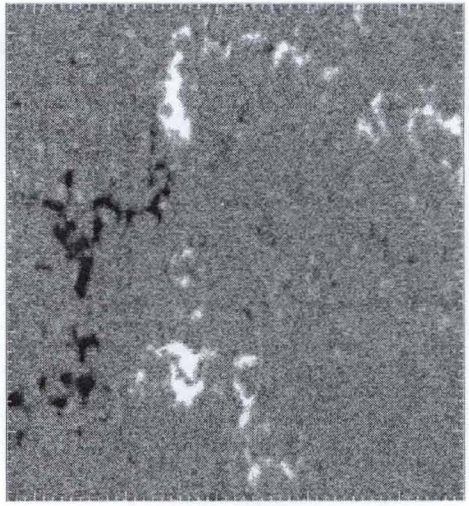

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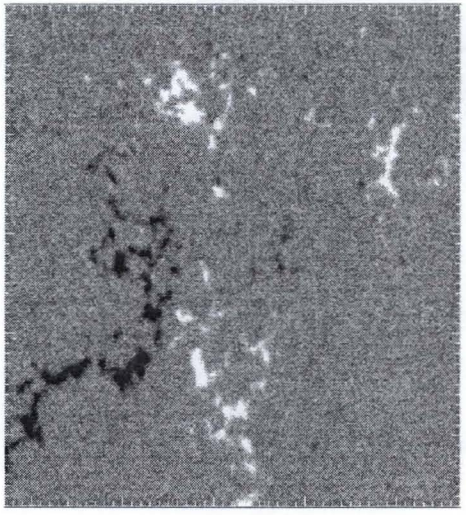

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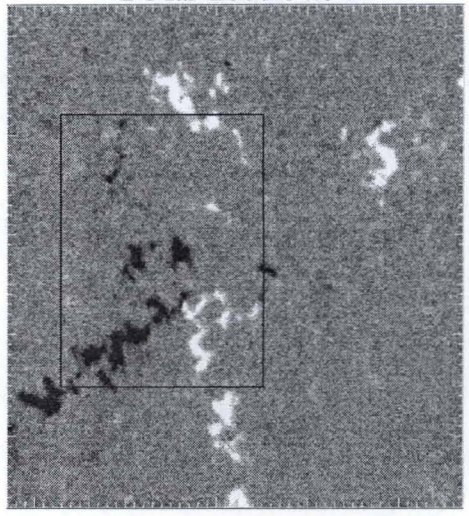

Sterling, Dublin 2007

Cancelation Energetics

- Field strength, B ~ 40 G in enhanced network in box.
- $V = 2'' \times 26'' \times 2''$
- f = 0.1
- Magnetic energy = $(B^2/8\pi)Vf \approx 4\times10^{27}$ ergs during six hours or less prior to the eruption.

It's no surprise that this is not enough energy to *power* the eruption, but it could be enough cancelation for instability to kick in, or for runaway to take over (e.g., van Ballegooijen & Martens, Moore & Roumeliotis, Rust & Kumar, Lin & Forbes).